Postprint of: Dawidowicz A., Kulawiak M., Zysk E., Kocur-Bera K., System architecture of an INSPIRE-compliant green cadastre system for the EU Member State of Poland, Remote Sensing Applications: Society and Environment, Vol. 20 (2020), 100362, DOI: 10.1016/j.rsase.2020.100362

System architecture of an INSPIRE-compliant green cadastre system for the EU Member State of Poland

Agnieszka Dawidowicz[1], Marcin Kulawiak[2], Elżbieta Zysk[3], Katarzyna Kocur-Bera[4]
agnieszka.dawidowicz@uwm.edu.pl [1] (corresponding author), Marcin.Kulawiak@eti.pg.edu.pl [2]
elzbieta.zysk@uwm.edu.pl [3], katarzyna.kocur@uwm.edu.pl[4]

[1,3] Institute of Spatial Management and Geography, Faculty of Geoengineering, University of Warmia and Mazury in Olsztyn, Poland
[2] Department of Geoinformatics, Faculty of Electronics, Telecommunication and Informatics, Gdansk University of Technology, Poland
[4] Institute of Geodesy and Civil Engineering, Faculty of Geoengineering, University of Warmia and Mazury in Olsztyn, Poland

ORCID:
AD: https://orcid.org/0000-0002-8445-3095
MK: https://orcid.org/0000-0002-9124-5358
EZ: https://orcid.org/0000-0002-2793-6154
KK-B: https://orcid.org/0000-0001-7056-5443

Abstract

In response to the need for a sustainable agricultural policy for the purpose of supporting decision making in precise agriculture as well as agricultural threat mitigation, a concept agricultural information system called Green Cadastre (GC) was developed for the area of Poland. This innovative concept proposes to create a uniform GC, fit for the purpose of both administration as well as farmers, on a national scale. This article presents the concept system architecture of the proposed GC. The architecture has been developed on the basis of an analysis of current trends in geospatial IT as well as the state of INSPIRE Spatial Data Infrastructure and previously established requirements for the GC system. The proposed solution combines open data exchange protocols with Open Source technologies according to current international SDI standards in order to provide a flexible and cost-effective solution.

Keywords: green cadastre, agriculture, spatial data infrastructure, land administration system, GIS, INSPIRE

1. Introduction

Recent years have seen an increase in studies and reports of threats to agriculture, which may or have already resulted in a reduction in agricultural production (EC, 2018; Duong et al. 2019; Komarek et al., 2020). The major risk factors for agriculture are: globalization (van Meijl et al., 2006), progressing urbanization (Kalnay and Cai, 2003; Antrop, 2004; Cohen, 2006), decreasing availability of cultivable land for food production (Benayas et al., 2007; Iavicoli et al. 2017; Leń, 2018; Wójcik-Leń and Sobolewska-Mikulska, 2017; Renwick et al., 2013), water contamination and flood risk (Islam, Managi, 2018; Murtaza el al. 2019), as well as climate change (Campbell et al. 2016; Wheeler, 2017). In view of these problems, various international norms and treaties, such as the Millennium Development Goals (UN, 2000), Sustainable Development Goals (UN, 2015) as well as protective mechanisms for controlling land sales (Klimach et al. 2019) and financing programs (EC, 2020a; Hughes, 2019; Zaharia, Mihai, 2018), have been proposed to maximize the effectiveness of procedures aiming to prevent excessive conversion of farmland for non-agricultural use. All activities that support agriculture need up-to-date and complete information systems (Sørensen et al. 2010; Maes et al. 2012). Studies have shown that the implementation of a dedicated agricultural production information system can bring numerous benefits by facilitating data exchange between public registers, monitoring of agricultural land, control of agricultural production, prevention of conversion of agricultural land into non-agricultural land and extension of existing databases on agricultural land (Fountas et al., 2006; Rose et al., 2016). A detailed literature analysis of the following keywords: information system for agricultural policy support, information systems for agriculture, Geographic Information Systems (GIS) for agriculture, farm management information system (FMIS), farm software (FS), decision support systems for agriculture and information management in agriculture, or combinations of these showed that there are many concepts and ideas for information systems supporting innovative agriculture, smart farming, precision agriculture, site-specific farming, site-specific crop management, prescription farming, satellite farming and land decision making. They range from development of software dedicated for farm management, which provides support for bureaucratic tasks such as managing production records and bookkeeping (Nikkilä et al. 2010; Fountas et al. 2015; Abubakar and Ahmad, 2017) to creating generalized models of Information and Communications Technology (ICT) applications for precise farming purposes (Kaloxylos et al. 2012; Kruize et al. 2016). Several works focus on the application of sensor networks and Internet of Things (IoT) devices for enhanced monitoring and management of farmlands (Zhang et al. 2002; Adamchuk et al. 2004; Lakshmisudha et al. 2016; Köksal and Tekinerdogan, 2019), while other solutions involve applications of remote sensing for precise agriculture (McCabe et al. 2016; Khanal et al. 2017). Solutions involving Geographic Information Systems (GIS) have a wide variety of applications, ranging from creating soil maps for precise farming based on in-situ measurements (Kingsley et al. 2019), through assessment of land suitability for agricultural applications (AbdelRahman et al. 2016; Ahmed et al. 2016; Montgomery et al. 2016; Yalew et al. 2016) to concept systems for monitoring of agricultural areas (Dunaieva et al. 2018). In essence, existing solutions consist primarily of purpose-built systems, dedicated for particular users (either farmers, scientists or policy makers) and applications (farm management, land management, crop monitoring, planning and optimization of farming duties or integration of farming sensors and software). None of the presented systems constitute a comprehensive tool for collecting, management and analysis of agricultural data which would provide information supporting all interested stakeholders. Therefore in response to the need for an information system to support agricultural policy and production in Poland, a basic concept of such a system was developed and given the moniker of Green Cadastre (GC) (Zysk et al. 2020). This research was the initial stage in the development of a technical specification for the GC. The conceptualization of such a comprehensive system for agriculture required a thorough analysis of legal, organisational as well as technical possibilities and needs in order to meet the principle of fit-for-purpose information system (Enemark et al., 2014). The general GC functionalities have been designed based on an analysis of user requirements as well as existing procedures in order to provide a multifunctional and universal system. The resulting concept assumes that the GC system should have the following objectives: promoting the exchange of information on rural areas between organisations at different levels of the public administration system, supporting cooperation between national and international institutions, creating a comprehensive database of rural areas and the agriculture production, as well as processing and analysis of the collected data. It was further assumed that the Green Cadastre should meet the information needs of public administration and society, with particular emphasis on data quality, accuracy and coherence, consolidation of data from different sources, development of rural development indicators, cooperation between institutions, collection of data in one place, wide access to data, comparison of national data with EU (European Union) data, development of guidelines for collecting national agricultural data in the INSPIRE geoportal, presentation of information in a simple and transparent way, publication of data generated by different institutions and adaptation of data to the needs of different user groups. Since a networked system supports more effective and sustainable achievement of common goals than a collection of dispersed independent systems (Roling, 1988), it is crucial that the GC system provides methods for tight integration with existing agricultural information systems. It is particularly important that the system supports individual farmers, either by providing a set of basic services for land management, or by providing an extension to existing precise farming software by making its databases remotely accessible through open data exchange protocols. In this context, the Green Cadastre concept is particularly innovative because currently no other system in the world combines the interests of governments as well as individual farmers using a common land administration technology (which is also part of the national spatial data infrastructure), to integrate and exchange data between many sources. This solution fits into and actively develops the technological perspective on the evolution of Spatial Data Infrastructures (SDIs), which involves combining big data produced by society and commercial services with institutional data (Kotsev et al. 2020).

To sum up, this paper aims to provide a continuation of research in this area by proposing an architecture of the Green Cadastre system which would fit into the existing national SDI, enable future expansion and allow for integration of data created by individual farmers.

2. Materials and Methods

This section describes the existing Spatial Data Infrastructure situation in the EU Member State of Poland and discusses the emerging data sources which may be used in the proposed Green Cadastre system.

2.1. The Spatial Data Infrastructure in Poland

The need to have integrated spatial data at not only national but also international level gave rise to the idea of a Spatial Data Infrastructure (Williamson et al. 2003; Dawidowicz, Źróbek, 2016). Since then, SDIs have been successfully launched on a continental level (Merodio Gómez et al. 2019; INSPIRE, 2007). In general, a spatial data infrastructure can be understood as a source of geographic information which provides tools for browsing and searching of the available data. A more accurate definition describes the SDI as the sum of several elements (Fig. 1). These include GIS databases, formal agreements that provide data access, open standards and technologies that enable access to this data, as well as tools for data search and presentation. Interoperability is achieved by using open data access standards over well-known internet protocols (GEOPORTAL, 2016).

SDI = GIS + Internet + Standards + Interoperability + Agreements

Figure 1. SDI definition. Source: own elaboration on the basis of GEOPORTAL (2016)

Assuming that the GC would be a uniform system deployed at the country (European Member State) level, it should directly interface with the national Land Administration System (LAS). LAS is the backbone of the national infrastructure for the implementation of sustainable land policies and land management strategies. It enables comprehensive access to information about geographical objects as well as land tenure rights, restrictions and responsibilities (Dawidowicz and Źróbek, 2018). As part of the national SDI, LAS consists of institutional arrangements, a legal framework, processes, standards, land information databases coupled with management and dissemination systems, resource allocation technologies, land market and valuation procedures, land use control methods, and the creation of equitable interests in land (Williamson et al., 2010). According to the United Nations Committee of Experts on Global Geospatial Information Management (UN, 2015), well-designed land administration systems operating on geospatial data deliver a range of benefits to society in terms of support of governance and the rule of law, alleviation of poverty, security of tenure, support for formal land markets, security for credit, support for land and property taxation, protection of state lands, management of land disputes, as well as improvement of land use planning and implementation.

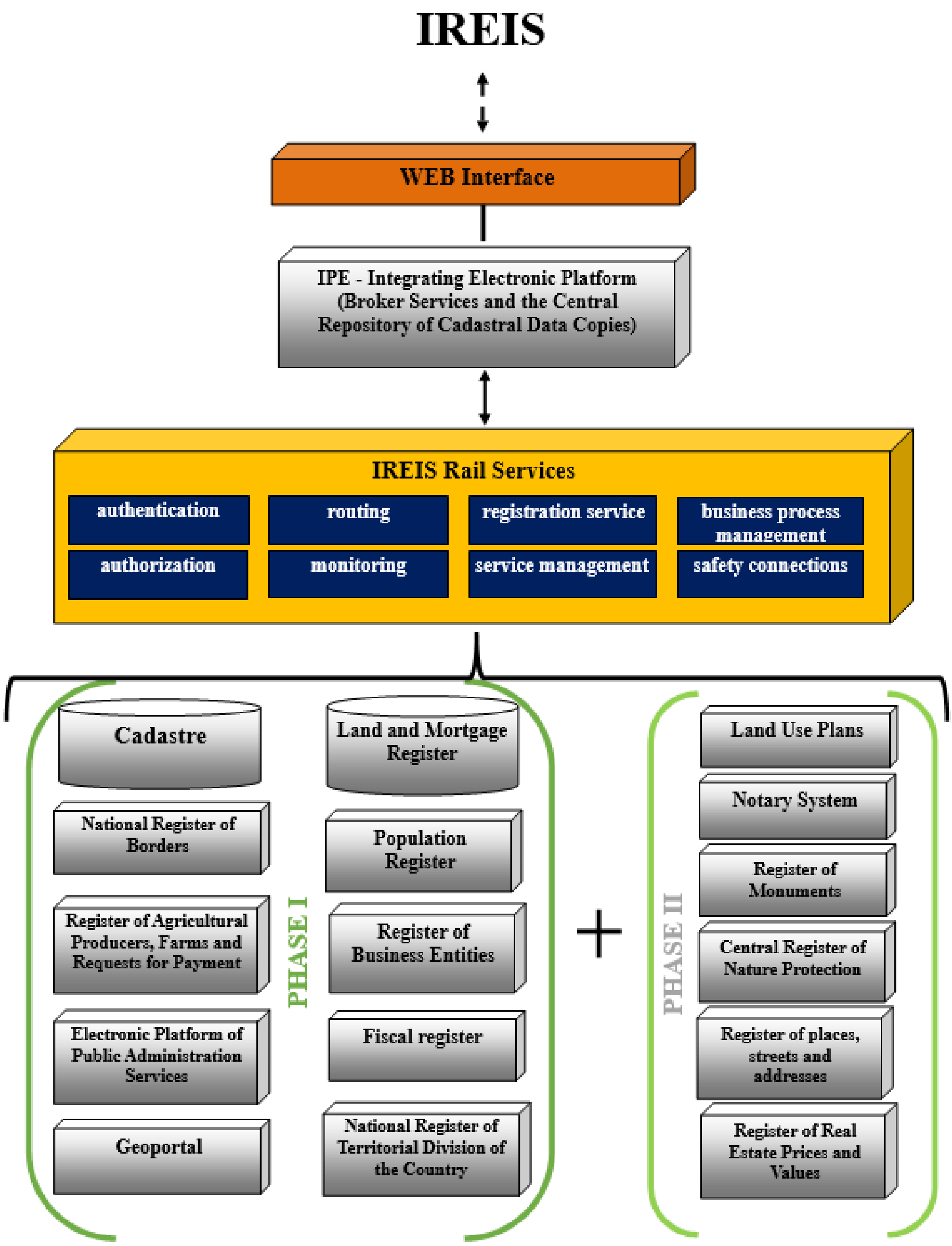


Figure 2. Functional architecture of the IREIS. Source: Own elaboration on the basis of the Regulation of the Council of Ministers of 17 January 2013 on the Integrated Real Estate Information System.

Those systems enable the application of land policies for the purpose of fulfilling political and social objectives as well as achieving sustainable development (UN-GGIM, 2015). LAS created in different countries guarantee the harmonization of global data in line with the Land Administration Domain Model (LADM) and ISO standard 19152 (Lemmen et al.2015; Bydłosz, 2015). In Poland, the LAS concept is being implemented in the form of the Integrated Real Estate Information System (IREIS) on the basis of the Regulation of the Council of Ministers of 17 January 2013 on the Integrated Real Estate Information System. The various elements of IREIS, including databases and services, are being implemented in phases (Fig.2).

The IREIS aims to integrate the databases of many public registers, including cadastre, land register, tax register and land-use plans, for the purpose of providing effective support for other systems and economic processes. Access to the system is available to both authorities as well as citizens (albeit the latter cannot access the full system functionality). While IREIS provides a wide array of capabilities, as far as green cadastre information is concerned it is currently limited by the available tools and data sources. In this context, in order to reduce feature redundancy, the developed Green Cadastre should directly interface with the IREIS framework and act as an extension of the existing functionality.

2.2. Data sources for the Green Cadastre

The previous research has established that the GC will rely on advanced ICT (IREIS platform) and GIS tools to address the demand for spatial information and support most procedures in the process of managing agricultural land. Moreover, the GC should deliver the following functionalities: data processing and analysis, data visualization, data exchange, generation of reports, generation of information materials, predictions, warnings, and alerts (Zysk et al. 2020). In the initial phase the GC databases should contain the following 14 data groups: Address data, Physical properties of land plot, Ownership (Rights, Restriction Responsibilities), Land-use types, Local policy, Infrastructure data, Soil and water conditions, Nature protection types, Climate, Environmental pollution and threats, Agricultural production, Roads, Ecosystem services and Economic data. These datasets have various applications for sustainable rural development, and can serve as reference layers for production of other types of data. For instance, individual farmers may use them to plan changes in agricultural production, seed orders, preplanting, planting, cultivation, harvesting, storage, processing, quantity and type of applied fertilizer, irrigation type as well as monitor food safety and quality, soil nutrient supply, soil pH (repeated) and others. The GC would be a flexible tool that could be developed successively with big data obtained from remote sensors and Internet of Things (IoT) devices depending on stakeholder needs. Out of the total number of 14 data layers, the IREIS can provide comprehensive access to 4 datasets (Address data, Ownership, Land-use types, Nature protection types) and partial access to 7 datasets (Physical properties of land plot, Local policy, Infrastructure data, Soil and water conditions, Agricultural production, Roads, Ecosystem services). The remaining 3 datasets (Climate, Environmental pollution and threats, Economic data) contain dynamically changing information such as temperature, precipitation, vegetation health (Climate), alerts concerning threats to vegetation (Environmental pollution and threats) and Farm income and value (Economic data), and as such they need to be obtained from other sources. The datasets which are not available through the IREIS could be integrated directly in the Green Cadastre submodule. However, data for SDIs is generally collected through precise field measurements, which traditionally could only be conveyed by large companies and institutional bodies. Due to the involved costs, some SDI datasets are often not being updated over prolonged periods of time, resulting in a progressing reduction of their credibility caused by the cumulation of land changes made in the real world. This is particularly true in case of raster datasets, which, unlike vector data such as parcel borders, cannot be partially updated in real time. This being said, the recent broad introduction of low-cost spatial sensors has provided new opportunities even for smaller entities to produce and collect thematic spatial data. Constellations of Micro- and Naonsatellites provide Earth Observation capabilities at a fraction of the price of traditional (military, governmental and private) systems, while Unmanned Aerial Vehicle (UAV) platforms equipped with passive as well as active sensors have become a valuable source of data for a completely new wave of disciplines and applications. At the same time, the latest generation of state-sponsored satellite sensors has democratized access to high quality remote sensing data through the European Space Agency's Sentinel Programme (EC, 2020b). While remote sensing data has previously been available free of charge, the Sentinel programme has provided a considerable step up in data quality and availability. Beforehand, freely available satellite imagery of the land and sea could only be obtained from sensors operated by the National Aeronautics and Space Administration (NASA). These included the Moderate Resolution Imaging Spectroradiometer (MODIS) satellites, which deliver on average a single image per day at a very limited resolution of 250 m per pixel, as well as the Landsat family of satellites which deliver a resolution of 30 m per pixel (which can be panchromatically sharpened to 15 m per pixel), but only revisit the same area approximately once a week. In comparison, the Sentinel-2 family of satellites, which produce high resolution multispectral Earth Observation data in the visible, Near Infrared and Short-wave Infrared spectra, provides a spatial resolution of 10 m per pixel and a temporal resolution of about two images per week. The Sentinel programme also encompasses other missions, which currently include Sentinel-1, which provides radar imaging of land and sea. and Sentinel-3, which provides other sensing instruments which, among others, enable monitoring of aspects such as temperature, water vapour and ocean colour. In consequence, the Sentinel sensors form a reliable foundation for day-to-day land monitoring. The Sentinel missions are operated by the European Space Agency in cooperation with the European Commission within the Copernicus Programme. The Copernicus Programme aims to provide high quality global Earth observation data for the purposes of environmental management, climate change mitigation, and ensuring civil security (European Space Agency 2020). Once fully operational, Copernicus will generate over 25 PB of data annually, thus creating the largest environmental satellite monitoring system ever created (Bai et al., 2017). By definition, Copernicus data products are free of charge and available under an open license (EC, 2019), which makes them a very flexible source of up-to-date information regarding land use.

2.3. Required functionalities of the Green Cadastre

The development of the software architecture of the proposed Green Cadastre system was preceded by a detailed analysis of the state-of-the-art in the area of architectures and applications of Geographic Information Systems, including spatial data structures and geographic data exchange protocols, as well as their existing implementations in the national land administration system. The structure of the analytical process is presented in Figure 3.

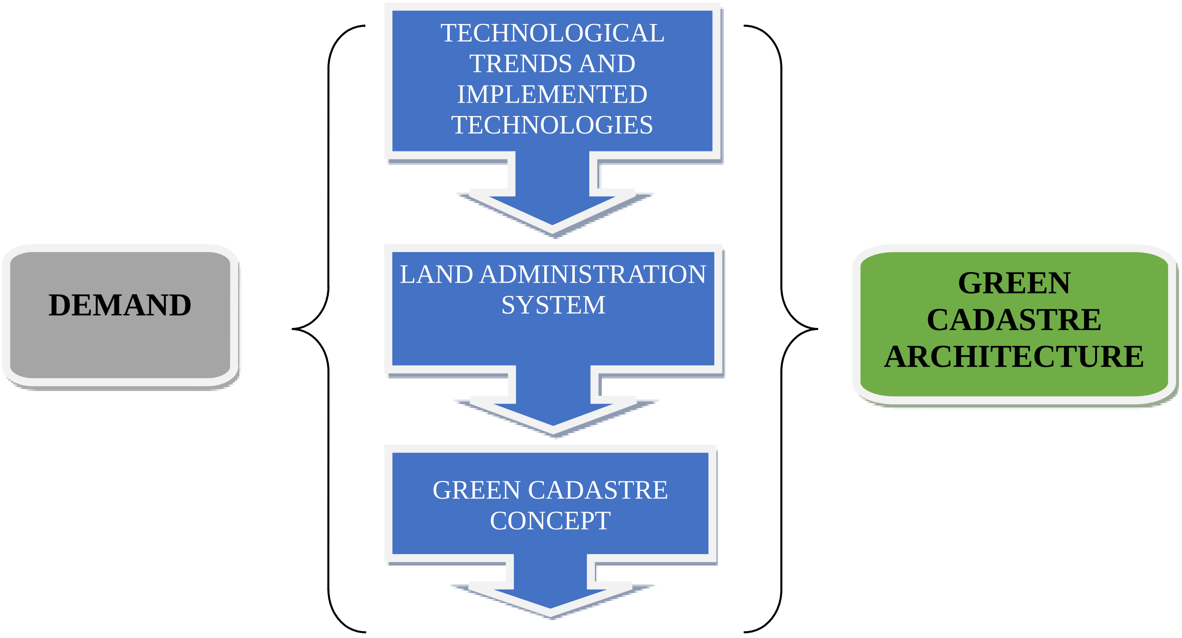
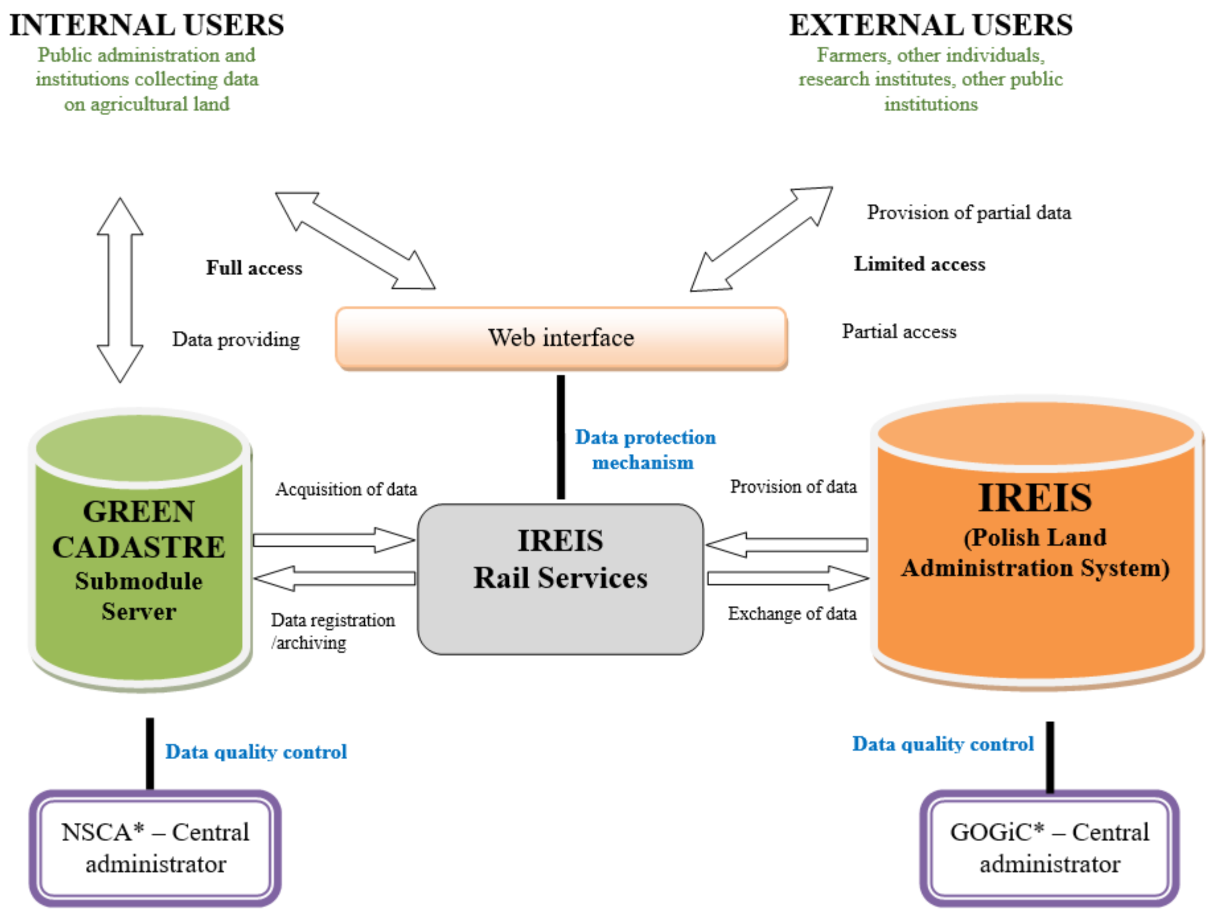


Figure 3. Structure of the analytical process. Source: own elaboration.

The architectural solution for the GC was based on the general GC concept (Zysk et al. 2020), which stated that the proposed system should be based on the existing data registers and technologies to eliminate redundancy, save time and minimize costs. Moreover, when designing the databases and general system architecture, the authors took into account the fact that technology is constantly evolving, with new software and hardware solutions cyclically replacing existing ones. Therefore, the presented architecture is based solely on open standards and well-established and dynamically developing Open Source technologies, which should ensure its long-term sustainability. Moreover, an architecture based on open standards and technologies should be more easily adaptable to the needs of different stakeholders in a flexible and inclusive way. This is particularly important because the proposed system should provide compatibility with solutions and technologies already implemented in the national Integrated Real Estate Information System (IREIS). As a consequence, the proposed design of the GC system around open technologies enables it to interface with the IREIS and act as a dedicated submodule (Fig.4).



*IREIS – Integrated Real Estate Information System
*NSCA – National Support Centre for Agriculture
*GOGiC – General Office of Geodesy and Cartography

Figure 4. Data flow in the Green Cadastre. Functional architecture of the GC. Source: Zysk et al. 2020.

3. Results - the proposed architecture of Green Cadastre

Taking into account the aforementioned system requirements, the developed architecture of the GC and its elements has been designed to realize the following system functionalities:

- the GC should provide capability for data processing and analysis, data visualization, data exchange, generation of reports, generation of information materials, predictions, warnings, and alerts;
- the GC should be an integral part of the national SDI, directly interfacing with the IREIS;
- core GC functionality should be made available to the public to support social participation and promote the development of a spatially enabled society;
- authorized users should be able to report invalid or missing data;
- the GC should be accessible through a web application compliant with Desktop computers as well as mobile devices such as smartphones and tablets;
- contents of the GC database should be made available through protocols conforming to Open Geospatial Consortium (OGC) standards, so that they may be accessed through any compatible software;
- data should be visualized in layers with a clear legend to generate maps with customized content for different purposes;
- the solution should be built using open technologies, so that it may be easily adopted to suit any newly introduced changes.

In the above context, the proposed architecture of the Green Cadastre system is presented in Fig.5.

The proposed architecture of the Green Cadastre system directly interfaces with the IREIS rail services, which allow access to several public registries such as LAS and Electronic Platform of Public Administration Services (ePUAP). The former contains the majority of datasets required for GC operation, as explained in the previous section. The latter is a nationwide platform for communication of Polish citizens with public administration, which can be used to provide user authentication services. Since the majority of GC layers will be obtained from their original sources in the IREIS through the existing SDI, only a specific subset of new data types (local climates, environmental hazards and economic data) will be kept in the GC database. In this context, the GC-specific thematic layers would be integrated and disseminated by means of GeoServer (http://geoserver.org), which is a dynamically developing Open Source GIS server. The GeoServer fully supports OGC Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS) and Web Feature Service Transactional (WFS-T) protocols. New information may be integrated in GeoServer from PostGIS, Shapefile, ArcSDE, DB2, Oracle, VPF, MySQL, MapInfo, and Cascading WFS data sources, supported through the Open Source GeoTools library (http://www.geotools.org). In addition, the software can render raster and vector maps in Joint Photographic Experts Group (JPEG), Graphics Interchange Format (GIF), Portable Network Graphics (PNG), Scalable Vector Graphics (SVG), Geographic JavaScript Object Notation

(GeoJSON), Geographically Encoded Objects for RSS feeds (GeoRSS) and Portable Document Format (PDF) formats, which provides a wide range of options for data dissemination.

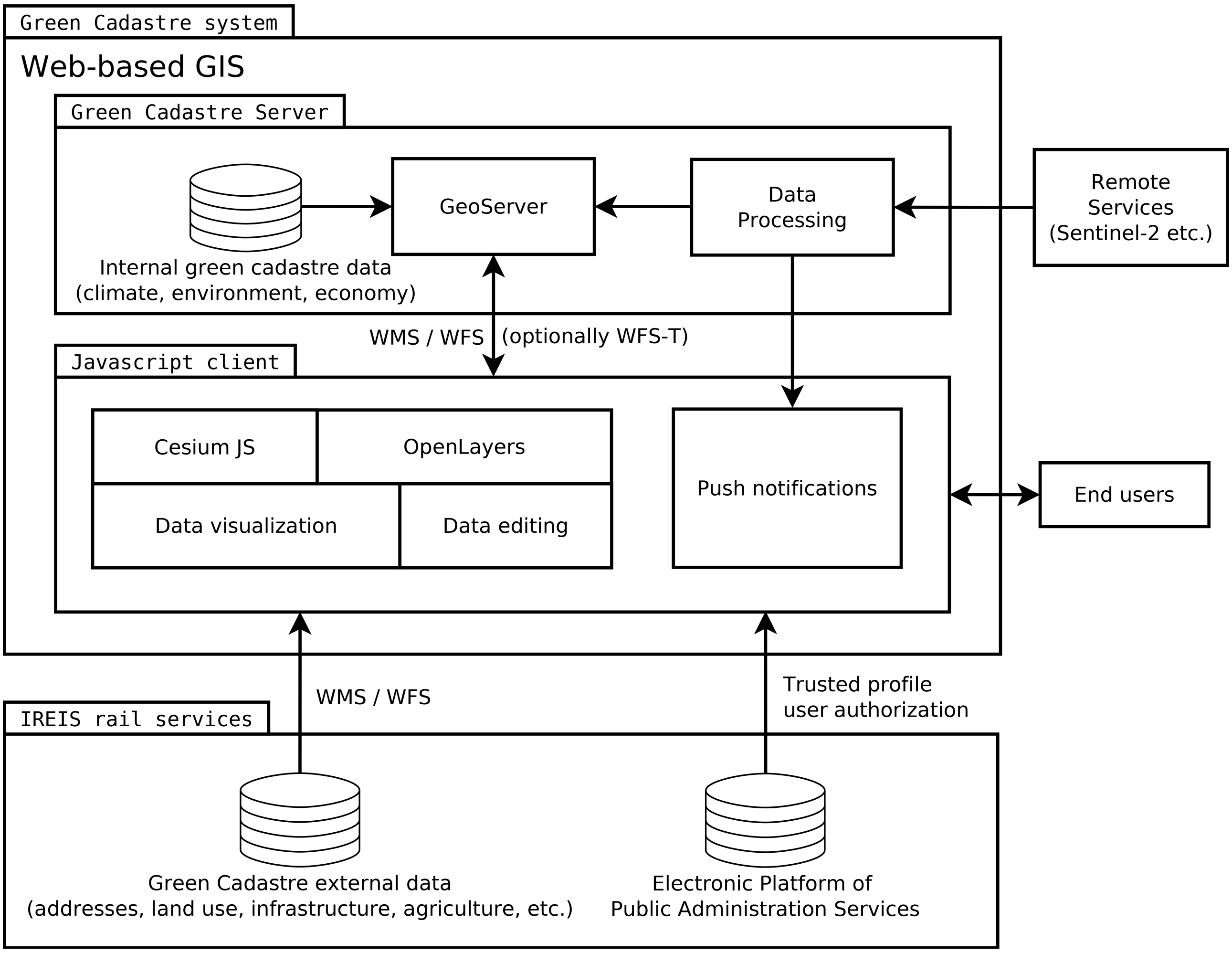


Figure 5. Proposed architecture of the Green Cadastre system.

The presentation style of every layer stored in the GeoServer database can be individually customized using Styled Layer Descriptor (SLD) files, which can be dynamically swapped and altered during web queries. Because the GeoServer supports an embedded European Petroleum Survey Group (EPSG) database, the stored data may be reprojected for integration with a multitude of map types, which may be useful for users interacting with data directly through OGC protocols instead of the system client. The green cadastre data could be accessed by means of WMS (for read-only presentation), WFS (which would enable remote processing of Green Cadastre data) or WFS-T (which would enable remote data update, and therefore should only be made available to trusted institutions such as designated administration representatives). The Green Cadastre system would also implement server-side procedures which could use data from remote services to obtain new information and integrate it with the thematic layers of the GC database through the Data Processing module. The remote datasets integrated within the system could include:

- Sentinel-2 satellite image repositories, eg. Sentinel Open Access Hub (scihub.copernicus.eu),

- Results of Numerical Weather Model predictions, obtained eg. from the National Research Institute of Meteorology and Water Management (www.imgw.pl),

- Latest Digital Terrain Model (DTM) data, obtained eg. from the IT system of the Country's Protection Against Extreme Hazards (ISOK) (www.isok.gov.pl),

- Latest Farm income and value data, obtained from the Farm Accountancy Data Network (FADN) database (ec.europa.eu/agriculture/rica).

The data processing and integration procedures could be performed periodically whenever new relevant data appears, producing up-to-date information regarding agricultural areas. These could include latest background maps of land use and soil state, weather forecasts for possible flooding and drought, as well as analysis of vegetation and crop health. Certain results of those procedures could then generate relevant alerts for the end users through the system's Push notifications module. The push notification functionality could be realized by means of Dynamic Hypertext Markup Language (DHTML), eg. through the HTML5 Notification API. This would allow remote users of the system to be notified whenever a relevant event (such as a warning about forecasted flooding of the user's parcel) has been detected by the server's Data Processing module.

Remote users could access the Green Cadastre data through the Web-GIS client, implemented in HTML5 javascript technology. As it can be seen in Fig. 5, the client integrates two leading Web-GIS javascript libraries in the form of OpenLayers (http://openlayers.org) and Cesium (https://cesiumjs.org). Open Layers is an Open Source object-oriented library for displaying two-dimensional map data in most modern web browsers, with no server-side dependencies. The library implements a constantly evolving JavaScript API for building rich web-based geographic applications by means of industry-standard methods, such as the OGC WMS and WFS protocols. OpenLayers is a mature solution which has proven its merit in cadastral applications by providing a wide array of tools for remote data presentation, editing and analysis (Dawidowicz & Kulawiak, 2018). Cesium, on the other hand, is an Open Source javascript library for 3D visualization of the Earth based on the World Geodetic System '84 (WGS84) ellipsoid with overlaid DTM and textures obtained eg. from satellite images. Cesium provides excellent rendering performance of complex 3D scenes by using hardware acceleration through the Web Graphics Library (WebGL) standard. The library provides support for external data sources such as WMS, and implements means of navigating the 3D map using touch based controls in addition to keyboard and mouse. Because Cesium does not yet support the WFS protocol, Green Cadastre data editing would need to be realized in 2D using OpenLayers. However, future developments could enable simplification of the client by implementing the entire functionality with only one Web-GIS library. Using Open Source HTML5 technologies for building the client would also provide the ability to share the codebase between the desktop and mobile versions of the application. In particular, aside from being available in the form of a mobile website, the web client could also be converted to the form of a mobile application using a middleware framework such as the Open Source Convertigo (www.convertigo.com). This solution would not only improve client code maintenance by unifying the codebase, but it could also provide full Web-GIS functionality (including data editing and analysis) inside a Smartphone app (Kulawiak, Wycinka, 2017).

4. Discussion & proof-of-concept

The processing and integration of Remote Sensing data in the GC Data Processing module would provide up-to-date information regarding the state of rural areas. While regular LIS are built with the use of high quality data such as high precision cadastre information as well as orthophoto maps with 1 m - 5 m resolution, this information is often collected during an expensive in-situ survey. Thus, should this information become outdated, bringing the system's database up to date requires spending a considerable amount of financial resources to repeat those measurements. In consequence, a LIS which contains data regarding a dynamically developing area is at a risk of quickly becoming obsolete. This issue may be alleviated to some extent by providing automated integration and processing of the freely available Sentinel-2 satellite images in the GC system's Data Processing module. The module would acquire the latest satellite images from the Sentinel Hub servers, analyse their quality (in order to ensure good visibility and low cloud cover) and process them into atmospherically corrected Level-2A datasets with a resolution of 10 m per pixel. The images would then be registered in the GC GeoServer module in the form of a good quality up-to-date background layer, which would complement the outdated high quality orthophotomaps.

A proof of this concept has been created for the agricultural district of Stawiguda in the Polish City of Olsztyn. Figure 6 presents an image from the Stawiguda LIS, depicting land use parcels overlaid on the orthophotomap of the area. Figure 7 presents the same vector layer overlaid on an atmospherically corrected Level-2A image obtained from a Sentinel-2 satellite on 26.08.2019. The Sentinel-2 image, although of noticeably lower quality, depicts the current state of the area in a much more precise manner. This is exemplified by the visible investment activity in the North-Western part of the image, as well as the new road infrastructure in the centre of the image, both of which are missing from the official orthophotomap.

Figure 6. An image from the Land Information System of Stawiguda, Poland, depicting land use parcels overlaid on an orthophotomap of the area. Although the vector map shows an outline of a new road, the background map does not properly represent it.

Figure 7. The Stawiguda land use parcels overlaid on an image obtained from a Sentinel-2 satellite on 26.08.2019. The new road and other recent investment activities are properly represented.

Aside from providing up-to-date background imagery, the Sentinel-2 datasets which have been integrated in the system database could then be further processed to perform semi real-time analyses of the state of particular parcels. For instance, data related to local climate could be obtained via automatic computation of Normalized Differential Vegetation Index (NDVI) (Rouse et al., 1974) or Leaf Area Index (LAI) (Asrar et al., 1984). These indices are widely used for assessing the general state of vegetation, and have many particular applications such as remote monitoring monitoring of crop health or verifying whether the blooming period of the parcel vegetation matches the owner-declared type of plants. A sample visualization of Sentinel-2 NDVI-based vegetation state analysis in the context of IREIS land use parcels for the agricultural area of Nowy Dwor Gdanski is shown in Fig.8.

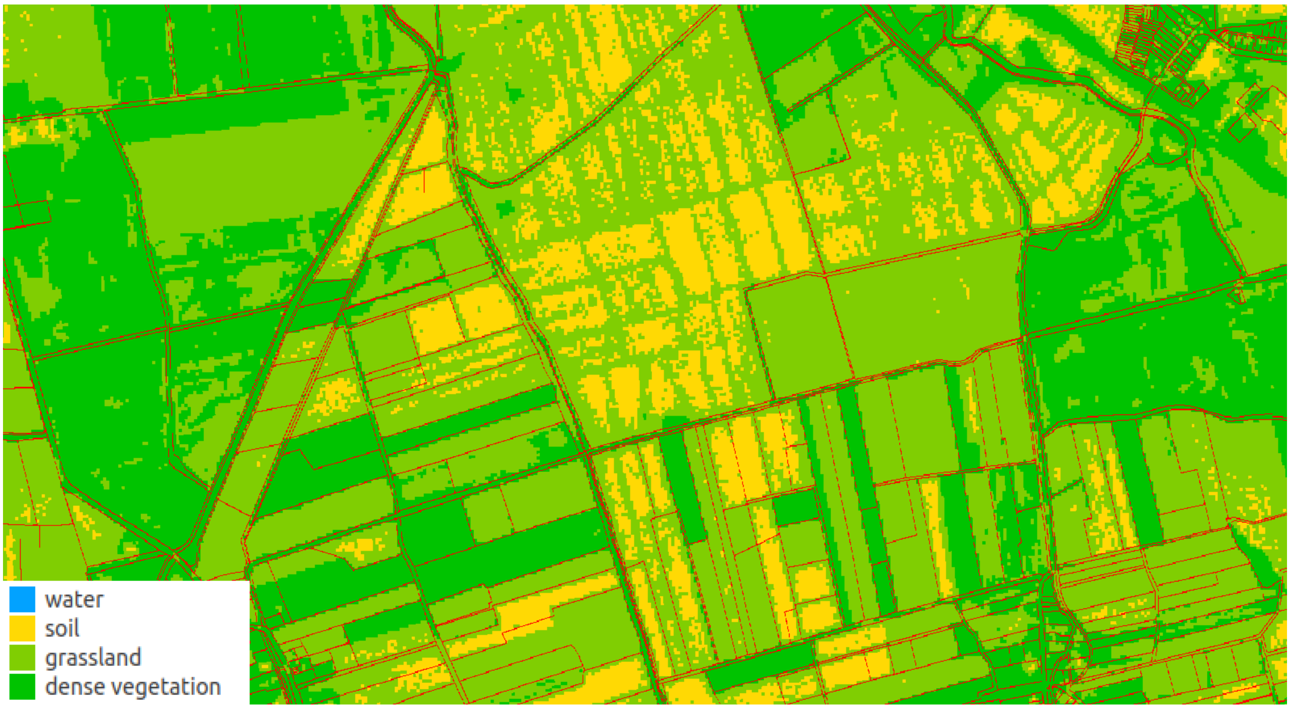


Figure 8. NDVI-based local climate analysis with overlaid land use parcels produced from Sentinel-2 satellite image of agricultural area in Nowy Dwor Gdanski, Poland, captured on 13.09.2016. Source: own study.

In addition, if the Cesium component of the GC system was granted access to the high-quality DTM of Poland produced in the course of the ISOK project, it could provide high-quality multidimensional data visualization and analysis. This functionality would permit eg. remote assessment of terrain slope and aspect for every Green Cadastre parcel before planning in-situ operations. Fig. 9 presents a sample 3D visualization of IREIS land use parcels near Nowy Dwor Gdanski, Poland, using the Cesium library and the Cesium Ion DTM. It should be noted that the Cesium Ion DTM has a much lower resolution than the ISOK DTM (30 m vs ~1 m), which means the visualization offered by the GC system would be of much higher quality.

Figure 9. Sample visualization of the slope and aspect of land use parcels in Nowy Dwor Gdanski, Poland, in the Cesium Web-GIS client, using the Cesium Ion dataset for illustrative purposes. Source: own study.

Because Cesium does not support WFS yet, WMS was used for the purpose of the above visualization. This means that client-side data manipulation would only be available in the OpenLayers client for the time being. However, the latest versions of Cesium already provide tools for data selection and query, which could be used eg. for receiving detailed information regarding selected parcels, or submitting cadastre data correction requests. In this context, when Cesium receives WFS-T support, the entire GC client functionality could be implemented using a single visualization library, and the OpenLayers part of the client could be phased out. While providing the entire GC client functionality strictly in 3D form could be considered excessive, it should be noted that the technology is already supported by the majority of Desktop-class computers as well as smart mobile devices (smartphones and tablets) on the market. Virtually any smartphone produced in the last 5 years should be capable of providing satisfactory performance when using the GC 3D client, as it has been shown that even older models provide good rendering performance when displaying complex scenes in Cesium (Kulawiak et al., 2019). Figure 10 presents a smartphone using the Snapdragon 625 System-on-Chip (SoC), a mid-range chipset produced in 2016, rendering the ArcticDEM dataset through the Cesium library in Google Chrome mobile. Despite being a 4 year old mid-range device, the smartphone delivered excellent performance when rendering this complex scene through Javascript and WebGL in a mobile web browser.

Figure 10. A mid-range smartphone produced in 2016 can provide smooth rendering of 3D terrain in a web application created using the Cesium library. Source: own study.

Moreover, in addition to providing touch-based input for mobile use, Cesium also delivers mechanisms for conserving device energy. For instance, the library only renders new frames of animation when the displayed scene changes in some way (such as when the user pans the camera) (Kulawiak et al., 2019). This behaviour considerably reduces battery consumption, which is a crucial feature for smartphone applications.

Conclusions

The paper presents a novel concept of an INSPIRE-compliant Green Cadastre architecture, dedicated primarily for deployment in EU countries. The concept has been designed for the EU Member State of Poland via an interdisciplinary approach which combined geographical, agricultural and IT knowledge to develop a fully tailored solution. The proposed system is designated to act as an element of the existing land administration framework, and thus it interacts with presently available data and services through open standards such as OGC WMS and WFS. The proposed architecture of the GC system allows for integration and processing of data from external sources, such as Copernicus Open Access Hub, for the purpose of providing users with up-to-date information regarding climate characteristics such as temperature, precipitation and state of vegetation at every land use parcel. This design aims to encourage individual farmers as well as their organized groups to integrate the provided GC data streams as part of their own solutions for precise agriculture. Architectural openness ensures that the proposed GC system architecture fulfils current requirements while also taking into account possible future developments. The presented proof-of-concept has shown that the chosen architecture could allow for the full GC functionality, including 3D visualization, to be available even on relatively old smartphones and tablets. Moreover, due to the use of open data exchange formats as well as Open Source technologies, the proposed architecture is very flexible and cost-effective and can be easily adopted for use in different EU Member States, as well as other countries interested in implementing an open Green Cadastre data framework.

References

AbdelRahman, M.A., Natarajan, A. and Hegde, R., 2016. Assessment of land suitability and capability by integrating remote sensing and GIS for agriculture in Chamarajanagar district, Karnataka, India. The Egyptian Journal of Remote Sensing and Space Science, 19(1), pp.125-141.

Abubakar, M. S., & Ahmad, A. B. (2017). Development of Farm Records Software. Arid Zone Journal of Engineering, Technology and Environment, 13(6), 743.

Adamchuk, V. I., Hummel, J. W., Morgan, M. T., & Upadhyaya, S. K. (2004). On-the-go soil sensors for precision agriculture. Computers and Electronics in Agriculture. doi: 10.1016/j.compag.2004.03.002.

Ahmed, G.B., Shariff, A.R.M., Balasundram, S.K. and bin Abdullah, A.F., 2016, June. Agriculture land suitability analysis evaluation based multi criteria and GIS approach. In IOP Conference Series: Earth and Environmental Science (Vol. 37, No. 1, p. 012044). IOP Publishing.

Antrop M., 2004. Landscape change and the urbanization process in Europe. Landscape and Urban Planning, 67(1-4), 9-26, DOI: 10.1016/S0169-2046(03)00026-4.

Asrar, G.Q., Fuchs, M., Kanemasu, E.T. and Hatfield, J.L., 1984. Estimating Absorbed Photosynthetic Radiation and Leaf Area Index from Spectral Reflectance in Wheat 1. Agronomy journal, 76(2), pp. 300-306.

Bai, Y.; Jacobs, C.A.; Kwan, M.P.; Waldmann, C. 2017. Geoscience and the Technological Revolution [Perspectives]. IEEE Geoscience and Remote Sensing Magazine 2017, 5, 72–75.

Benayas J. R., Martins A., Nicolau J. M., Schulz J. J., 2007. Abandonment of agricultural land: an overview of drivers and consequences. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 2(57), 1-14, DOI: 10.1079/PAVSNNR20072057.

Bydłosz, J. (2015). The application of the Land Administration Domain Model in building a country profile for the Polish cadastre. Land use policy, 49, 598-605.

Campbell, B. M., Vermeulen, S. J., Aggarwal, P. K., Corner-Dolloff, C., Girvetz, E., Loboguerrero, A. M., ... & Wollenberg, E. (2016). Reducing risks to food security from climate change. Global Food Security, 11, 34-43.

Cohen B., 2006. Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. Technology in Society, 28(1-2), 63-80, DOI: 10.1016/j.techsoc.2005.10.005.

Dawidowicz, A., Kulawiak, M. 2018. The potential of Web-GIS and geovisual analytics in the context of marine cadastre. Survey Review, 50(363), pp.501-512. doi: 10.1080/00396265.2017.1328331

Dawidowicz, A., Zrobek, R. 2016. Hierarchical development of the spatial data infrastructures as a globalization trend. In 2016 Baltic Geodetic Congress (BGC Geomatics) (pp. 147-153). IEEE.
Dawidowicz A., Źróbek R., 2018. A methodological evaluation of the Polish cadastral system based on the global cadastral model. Land Use Policy, 73, 59-72. https://doi.org/10.1016/j.landusepol.2018.01.037.
Dunaieva, I., Mirschel, W., Popovych, V., Pashtetsky, V., Golovastova, E., Vecherkov, V., Melnichuk, A., Terleev, V., Nikonorov, A., Ginevsky, R. and Lazarev, V., 2018, December. GIS Services for Agriculture Monitoring and Forecasting: Development Concept. In Energy Management of Municipal Transportation Facilities and Transport (pp. 236-246). Springer, Cham.
Duong, T. T., Brewer, T., Luck, J., & Zander, K. (2019). A global review of farmers' perceptions of agricultural risks and risk management strategies. Agriculture, 9(1), 10.
EC, 2018. Directorate-General for Agriculture and Rural Development (European Commission) , ECORYS , Wageningen Economic Research. Study on risk management in EU agriculture Final report – Study. ISBN 978-92-79-65579-1, DOI 10.2762/387583.
EC, 2019. European Commission. Legal notice on the use of Copernicus Sentinel Data and Service Information, 2019. Available online: https://sentinel.esa.int/documents/247904/690755/Sentinel_Data_Legal_Notice (accessed on 21 February 2020).
EC, 2020a. Common agricultural policy funds. https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/financing-cap/cap-funds_en (Accessed 21.02.2020).
EC, 2020b. European Commission. Europe's eyes on Earth: Looking at our planet and its environment for the ultimate benefit of all European citizens, 2020. Available online: https://www.-copernicus.eu (accessed on 21 February 2020).
European Space Agency. 2020. "Copernicus, Overview". ESA. Available at: http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview3 Accessed on: 09.03.2020
Enemark, S., Bell, K. C., Lemmen, C. H. J., & McLaren, R. (2014). *Fit-for-purpose land administration : open access e-book*. (FIG-Publication; Vol. 60). Copenhagen: International Federation of Surveyors (FIG), p. 44.
Fountas S., Wulfsohn D., Blackmore B. S., Jacobsen H. L., Pedersen S. M., 2006. A model of decision-making and information flows for information-intensive agriculture. Agricultural Systems, 87(2), 192-210, DOI: 10.1016/j.agsy.2004.12.003.
Fountas, S., Carli, G., Sørensen, C. G., Tsiropoulos, Z., Cavalaris, C., Vatsanidou, A., et al. (2015). Farm management information systems: Current situation and future perspectives. Computers and Electronics in Agriculture, 115, 40–50. doi: 10.1016/j.compag.2015.05.011.
GEOPORTAL, 2016. Available online: http://geoportal.gov.pl/index.php?option=com_content&view=article&id=6&Itemid=19 (accessed on 03 March 2016)
Hughes, D. W. (2019). Financing the agricultural sector: Future challenges and policy alternatives. CRC Press.
Iavicoli, I., Leso, V., Beezhold, D. H., & Shvedova, A. A. (2017). Nanotechnology in agriculture: Opportunities, toxicological implications, and occupational risks. Toxicology and applied pharmacology, 329, 96-111.
INSPIRE, 2007. Directive 2007/2/WE of the European Parliament and Council, of March 14th 2007, establishing the infrastructure of Spatial Information in the European Community (INSPIRE) (OJ L 108, 25.4.2007, p. 1–14).
Islam, M., & Managi, S. (2018). Sustainable Adaptation to Multiple Water Risks in Agriculture: Evidence from Bangladesh. Sustainability, 10(6), 1734.
Kalnay E., Cai M., 2003. Impact of urbanization and land-use change on climate. Nature, 423, 528-531, DOI: 10.1038/nature01675.
Kaloxylos, A., Eigenmann, R., Teye, F., Politopoulou, Z., Wolfert, S., Shrank, C., ... & Nicole, H. (2012). Farm management systems and the Future Internet era. *Computers and electronics in agriculture*, *89*, 130-144.

Khanal, S., Fulton, J., & Shearer, S. (2017). An overview of current and potential applications of thermal remote sensing in precision agriculture. Computers and Electronics in Agriculture, 139, 22-32.

Kingsley, J., Lawani, S. O., Esther, A. O., Ndiye, K. M., Sunday, O. J., & Penížek, V. (2019). Predictive Mapping of Soil Properties for Precision Agriculture Using Geographic Information System (GIS) Based Geostatistics Models. Modern Applied Science, 13(10).

Klimach, A., Dawidowicz, A., Dudzińska, M., & Źróbek, R. (2019). An evaluation of the informative usefulness of the land administration system for the Agricultural Land Sales Control System in Poland. *Journal of Spatial Science*, 1-25. doi: 10.1080/14498596.2018.1557571.

Kruize, J. W., Wolfert, J., Scholten, H., Verdouw, C. N., Kassahun, A., & Beulens, A. J. M. (2016). A reference architecture for farm software ecosystems. Computers and Electronics in Agriculture, 125, 12–28. doi: 10.1016/J.COMPAG.2016.04.011

Köksal, Ö., & Tekinerdogan, B. (2019). Architecture design approach for IoT-based farm management information systems. Precision Agriculture, 20(5), 926-958.

Komarek, A. M., De Pinto, A., & Smith, V. H. (2020). A review of types of risks in agriculture: What we know and what we need to know. Agricultural Systems, 178, 102738.

Kotsev A., Minghini M., Tomas R., Cetl V., Lutz M. 2020. From Spatial Data Infrastructures to Data Spaces—A Technological Perspective on the Evolution of European SDIs. ISPRS Int. J. Geo-Inf. 2020, 9(3), 176; doi: 10.3390/ijgi9030176

Kulawiak, M, Wycinka, W. 2017. Dynamic signal strength mapping and analysis by means of mobile Geographic Information System. Metrology and Measurement Systems Volume 24, Issue 4, pp. 596-606. doi: 10.1515/mms-2017-0057

Kulawiak, M, Chybicki, A. 2018. Application of Web-GIS and Geovisual Analytics to Monitoring of Seabed Evolution in South Baltic Sea Coastal Areas. Marine Geodesy 41 (4), pp. 405-426. doi: 10.1080/01490419.2018.1469557

Kulawiak, M., Kulawiak, M., Lubniewski, Z. 2019. Integration, Processing and Dissemination of LiDAR Data in a 3D Web-GIS. ISPRS International Journal of Geo-Information, 8(3), p.144. doi: 10.3390/ijgi8030144

Lakshmisudha, K., Hegde, S., Kale, N., & Iyer, S. (2016). Smart precision based agriculture using sensors. International Journal of Computer Applications, 146(11), 36-38.

Lemmen, C., Van Oosterom, P., & Bennett, R. (2015). The land administration domain model. Land use policy, 49, 535-545.

Leń P., 2018. An algorithm for selecting groups of factors for prioritization of land consolidation in rural areas. Computers and Electronics in Agriculture, 144, 216-221, DOI: 10.1016/j.compag.2017.12.014.

Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J. P., ... & Bouraoui, F. (2012). Mapping ecosystem services for policy support and decision making in the European Union. Ecosystem services, 1(1), 31-39.

McCabe, M. F., Houborg, R., & Lucieer, A. (2016, October). High-resolution sensing for precision agriculture: from Earth-observing satellites to unmanned aerial vehicles. In Remote Sensing for Agriculture, Ecosystems, and Hydrology XVIII (Vol. 9998, p. 999811). International Society for Optics and Photonics.

Merodio Gómez, P., Pérez García, M., García Seco, G., Ramírez Santiago, A., & Tapia Johnson, C. (2019). The Americas' Spatial Data Infrastructure. ISPRS International Journal of Geo-Information, 8(10), 432.

Montgomery, B., Dragićević, S., Dujmović, J. and Schmidt, M., 2016. A GIS-based Logic Scoring of Preference method for evaluation of land capability and suitability for agriculture. Computers and Electronics in Agriculture, 124, pp.340-353.

Murtaza, G., Zia-ur-Rehman, M., Rashid, I., & Qadir, M. (2019). Use of Poor-quality Water for Agricultural Production. In Research Developments in Saline Agriculture (pp. 769-783). Springer, Singapore.

Nikkilä, R., Seilonen, I., & Koskinen, K. (2010). Software architecture for farm management information systems in precision agriculture. Computers and electronics in agriculture, 70(2), 328-336.

Renwick A., Jansson T., Verburg P. H., Revoredo-Giha C., Britz W., Gocht A., McCracken D., 2013. Policy reform and agricultural land abandonment in the EU. Land Use Policy, 30(1), 446-457, DOI: 10.1016/j.landusepol.2012.04.005.

Roling, N., 1988. Extension science: Information systems in agricultural development. CUP Archive.

Rouse, J.W., Jr., Haas, R. H., Deering, D. W., Harlan, J. C. 1974. Monitoring the vernal advancement and retrogradation (greenwave effect) of natural vegetation. Texas A & M University, Remote Sensing Center, pp. 1-10.

Sørensen, C. G., Fountas, S., Nash, E., Pesonen, L., Bochtis, D., Pedersen, S. M., ... & Blackmore, S. B. (2010). Conceptual model of a future farm management information system. Computers and electronics in agriculture, 72(1), 37-47.

UN, United Nations, 2000. United Nations Millennium Declaration, Resolution 55/2. Available at https://documents-dds-ny.un.org/doc/UNDOC/GEN/N00/559/51/PDF/N0055951.pdf?OpenElement. Accessed 5.04.2016.

UN, United Nations, 2015. Transforming our world: the 2030 Agenda for Sustainable Development. UE Sustainable Development Agenda, Resolution A/RES/70/1, pp. 35, Available at http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E. Accessed 1.07.2016.

UN-GGIM, United Nations Committee of Experts on Global Geospatial Information Management, 2015. The Application of Geospatial Information – Land Administration and Management UN-GGIM Version 3.1, 13 July 2015. Available at http://ggim.un.org/knowledgebase/KnowledgebaseArticle51948.aspx (accessed 02.03.2020)

van Meijl H., Van Rheenen T., Tabeau A., Eickhout B., 2006. The impact of different policy environments on agricultural land use in Europe. Agriculture, Ecosystems & Environment, 114(1), 21-38, DOI: 10.1016/j.agee.2005.11.006.

Wheeler, T. (2017). Climate change and agriculture: risks and opportunities to food and farming systems in the tropics. Agriculture for Development, 30, 58-60.

Williamson, I. P., Rajabifard, A., & Feeney, M. E. F. 2003. Developing spatial data infrastructures: from concept to reality. CRC Press. ISBN 0-415-30265-X, pp. 313

Williamson I. P., Enemark S., Wallace J., Rajabifard A., 2010. Land Administration for Sustainable Development. ISBN 978-1-58948-041-4, ESRI Press, p. 487.

Wójcik-Leń J., Sobolewska-Mikulska K., 2017. Issues related to marginal lands with reference to selected agricultural problematic areas. Journal of Water and Land Development, 35, 265-273, DOI: 10.1515/jwld-2017-0093.

Yalew, S.G., van Griensven, A., Mul, M.L. and van der Zaag, P., 2016. Land suitability analysis for agriculture in the Abbay basin using remote sensing, GIS and AHP techniques. Modeling Earth Systems and Environment, 2(2), p.101.

Zaharia, A., & Mihai, D. (2018). Overview on the financing of the EU agriculture. Calitatea, 19(S1), 575-581.

Zhang, N., Wang, M., & Wang, N. (2002). Precision agriculture - A worldwide overview. Computers and Electronics in Agriculture, 36(2–3), 113–132. doi: 10.1016/S0168-1699(02)00096-0.

Zysk, E., Dawidowicz, A., Nowak, M., Figurska, M., Źróbek, S., Źróbek, R., & Burandt, J. (2020). Organizational aspects of the concept of a green cadastre for rural areas. *Land Use Policy*, *91*, 104373. doi: 10.1016/j.landusepol.2019.104373