REVIEW OF AGRICULTURAL CADASTRE APPROACHES USING GEOMATICS FOR RURAL DEVELOPMENT

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ABSTRACT

The agricultural cadastre plays an essential role in land administration systems because it achieves the spatial integrity of farming parcels, guaranteeing food security, agricultural production and land tenure. The development of the urban–rural agricultural cadastre links technological advances with the use and integration of geomatic tools in its planning. However, problems include tenure vulnerability, land disputes, illegal settlements, little resource information (crop/water/soil) and territorial information. Spatial development differs between developed and emerging countries in urban and rural areas. This study analyses advances in agricultural cadastre development by reviewing scientific documents in Scopus and Web of Science, which use geomatics in various agricultural regions for rural development. The methodology consists of: (1) search strategy and studies selection; (2) multiple correspondence analysis with RStudio; and (3) interpretation and findings of agricultural cadastre developments using geomatics. The Czech Republic, Poland, Slovakia, Spain and Russia contribute the most to agricultural cadastre development. Thematic trends focus on land consolidation projects and cadastral estimation/ evaluation of agricultural land (23%), topology/use/management of agricultural territory (19%) and abandoned agricultural land spatial identification, suitability/inventory of the territory and agricultural landscape (12%). In addition, other less frequent uses contribute to property and tax administration, forest management, agricultural reorganisation and farm products cadastre. These studies seek to improve agricultural conditions, increase the agricultural operations profitability, crops spatial planning and rural reorganisation through projects that automate cadastral activities using geomatic tools such as geographic information systems (ArcGIS, QGIS, ArcMap), Remote Sensing (SPOT, Sentinel 1-2, Ikonos, Landsat 7-8) and remotely piloted aircraft system (unmanned aerial vehicles).

Keywords: agricultural cadastre, rural development, geomatics, multiple correspondence analysis.

1 INTRODUCTION

Rural development is associated with agricultural land use, forestry, agricultural production, traditional settlement and primary industries contributing to economic growth [1]. According to Long et al. [2] and Herrera-Franco et al. [3], this development has evolved from a productive approach to a comprehensive strategy considering industry, services, commerce, and rural economy diversification. Furthermore, rural settlements are essential for land use in rural development spatial distribution dynamics [4].

Rural development responds to local/regional problems that include social (demographic growth), economic (industrial transformation), political (territorial planning) and environmental (ecological conservation) challenges [5], [6]. Of these challenges, the decrease in the rural population stands out (23% less in the last 60 years) [7], and the world population growth in emerging countries (83% of the world population) [8]. Therefore, sustainable rural development policies are proposed that integrate the use/protection of agricultural land and urban–rural land use planning. These policies will contribute to the Sustainable Development Goals (SDGs) established by the United Nations to address food security problems (SDG 2).

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In addition, they use the agricultural cadastre for planning rural development and smart, sustainable communities (SDG 11) [9].

The agricultural cadastre is a parcel-based territorial information system related to agricultural land use, administration and management [10]. It is a tool that collects, processes and monitors data on agricultural territories, exploitation and cultivation practices to improve living conditions, food security and spatial distribution [11]. The purpose of the agricultural cadastre could be global, with significant differences depending on the country's origin, history, cultural development, regulations and geodetic practices [12]. For example, the European cadastre focused on tax collection and agricultural production capacity [13], while the Australian cadastre based on land security and tenure [14].

The cadastral map is the fundamental component of the agricultural cadastre, which focuses on georeferencing rural properties. These maps are cartographic records that consider the properties, dimensions, shapes, and spatial relationships between plots [15]. The cadastral map also promotes information exchange about rural areas between public administration organisations, agricultural production and support for farmers and decision-makers [16]. Furthermore, it integrates land administration systems (LAS) technologies based on geographic information systems (GIS) that respond to sustainable agricultural policies [17].

Geomatics considers geospatial technologies for collecting land administration data and updating traditional cadastres [18]. These technologies have given rise to a rapid and low-cost cadastre that affects land tenure security, territorial taxation, and land use administration [19]. For example, global navigation satellite systems (GNSS) and GIS provide road information such as contours, slopes and geolocation [20], [21], property registration and sustainable natural resource management [22]. In addition, images from unmanned aerial vehicles (UAV) and LiDAR evaluate changes in forest cover in agricultural territories [23], and satellite images through remote sensing (RS) determine the performance of cultivation for sustainable agricultural management [24], [25].

Some secondary agricultural cadastre studies show interest in land tenure, informal settlements and agricultural/irrigation management. For example, Salmerón-Manzano and Manzano-Agugliaro [26] analysed scientific publications based on land tenure between 1950 and 2020. This study highlights topics associated with social, environmental and agricultural/biological sciences, focusing on deforestation, forestry and agricultural land preparation in countries with the largest arable territory, such as the United States (USA), the United Kingdom (UK) and Australia. Also, Tija and Coetzee [27] analysed improvements in informal settlements through geospatial information related to physical, socioeconomic and boundary aspects. The most commonly used data collection tools/methods are global positioning systems (GPS), surveys and cameras. Theme trend evaluates observable characteristics such as infrastructure, public services and socioeconomic status.

Additionally, Murmu and Biswas [28] reviewed image classification techniques in crop mapping for planning, agricultural areas management and irrigation control. Supervised and unsupervised classification are predominant techniques. This study highlights the fuzzy classification used to categorise heterogeneous vegetation areas and concludes that crops identified from RS estimate irrigation needs. Crommelinck et al. [29] highlight the generalised cadastral workflow, which consists of processing, image segmentation, line extraction, contour generation, and post-processing. In addition, this paper highlights the identification of agricultural field boundary characteristics through aerial and satellite images (e.g., predominant satellites IKONOS and QuickBird).

Review studies related to the agricultural cadastre include landscape reconstruction through GIS, considering hydrology, agriculture, and forestry [30]; land concentration through artificial intelligence (AI) integration, GIS and advanced cadastral survey techniques

[31]; and agricultural territories formal tenure due to rural demographic growth [32]. However, the agricultural cadastre perspectives in rural sectors' economic/social/political/ environmental development through geomatic technology that contributes to sustainable agrarian territories are still unclear. Therefore, the research question arises: What are the technological advances of the agricultural cadastre and its application in the development and transformation of the rural environment?

This study aims to analyse, through a review of scientific documents in indexed databases such as Scopus and Web of Science (WoS), the different agricultural cadastre developments that use geomatics in various agricultural regions for rural development.

2 METHODOLOGY

This study applied bibliometric analysis and scientific literature review to explore spatial analysis methods, geomatic technological advances, and research trends of agricultural cadastre in rural development. Bibliometric analysis allows for identifying knowledge, domain and research trends in any field of knowledge [33], [34]. The methodology of this article begins with the formulation of the search equation in indexed databases of high scientific quality Scopus and WoS. These databases are multidisciplinary platforms with many scientific publications [35]. The advanced search used keywords, titles, abstracts, and Boolean operators (Fig. 1). This search was carried out in February 2024 and resulted in 1,725 documents. In data cleaning, 490 duplicate documents and 17 without records were eliminated, leaving 1,218 documents. Of these, 256 were excluded due to language other than English [36], considering 'Articles' document types (as they represent the majority of the results) [37], leaving a total of 584 documents. The systematic review process had two stages. First, it considered titles, abstracts, and keywords related to the agricultural cadastre in rural development. The second stage carried out a more in-depth analysis of the content of the selected articles, excluding 477 documents associated with other study approaches such as land certification, agricultural land use, agricultural land mapping and uncontrolled urbanisation. Subsequently, the Multiple Correspondence Analysis (MCA) used the studies that satisfied the inclusion criterion (107 documents). The objective is to configure the relationship between technologies, the development of agricultural cadastre, and their impact on rural development. The MCA is a method for analysing, describing, and summarising multidimensional data to understand variables that explain a fact [38]. Data treatment and analysis of results used the statistical program RStudio version R-4.1.2.

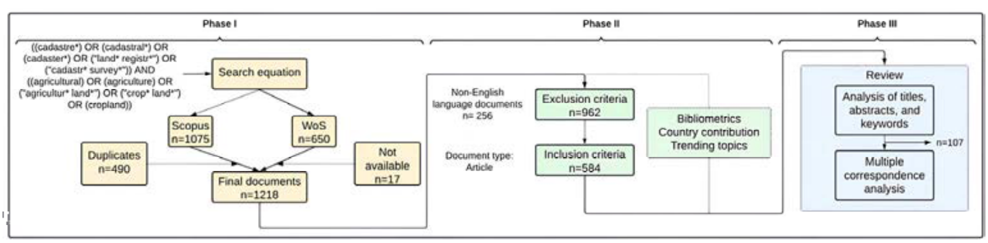


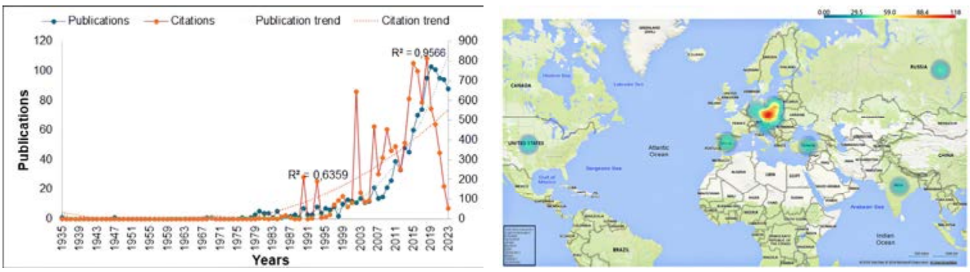
Figure 1: Flowchart of methodology phases.

3 RESULTS

3.1 Productivity and trending topics

3.1.1 Scientific contribution and influential countries

Fig. 2(a) shows the relationship between the number of publications and citations and the years from 1935 to 2023. The general trend of publications on the agricultural cadastre approach in rural development has been increasing. It began in the 1980s and reached the highest publication in 2019, with publications on the description and changes in rural landscapes formed by crops (vineyards), livestock, and forests [39], [40]. Furthermore, the global implementation of land consolidation projects to solve problems of land fragmentation by agricultural holdings [41]–[43].



(a) (b)

Figure 2: Scientific production. (a) Analysis of scientific publication trends and citations; and (b) Top ten most productive countries in agricultural cadastre studies in rural development.

Additionally, 83 countries published studies related to the field of knowledge. Much of this contribution comes from European countries (44.58%), Asian countries (24.10%) and American countries (16.87%) (Fig. 2(b)). Czech Republic is the most productive country (*n* = 112), followed by Poland (*n* = 79), Slovakia (*n* = 55), Spain (*n* = 42) and Russia (*n* = 41). These countries highlight their agricultural cadastre studies on changes in the farming landscape, limits, surface area, valuation of productive regions, monitoring of irrigation water use, forest management, detection of abandoned agricultural lands, land consolidation, and sustainable development of rural areas.

3.1.2 Trending

The tree map represents the frequency of the author's keywords related to the agricultural cadastre for rural development. In Fig. 3, the size of the rectangles represents the frequency of the author keywords, and the colours represent the interrelationship between studies. The relevant terms are 'agricultural land', 'GIS', 'land cadastre', 'land use', 'land consolidation', 'agricultural landscape', 'remote sensing', 'land use change', 'land management' and 'land registration'. 'Agricultural land' and 'climate change' include risk assessment studies on agroclimatic resources, agricultural landscapes and irrigated areas to contribute to climate change mitigation and adaptation. 'GIS' and 'land abandonment' suggest studies to monitor the abandonment of agricultural land use and forest succession through multi-temporal data and laser scanning to promote rural development and reduce risk to food security. 'Land cadastre' and 'land evaluation' include studies that evaluate land and agricultural systems

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dynamics by implementing an agricultural cadastre for local community development. ‘Land use’ and ‘random forest’ suggest crop-type detection studies through aerial image classification and multi-temporal satellite and pixel-based mapping to contribute to cropland productivity. ‘Soil quality’ includes studies on the suitability of agricultural cadastral lands for implementing ‘land consolidation’ projects in agricultural management decision-making.

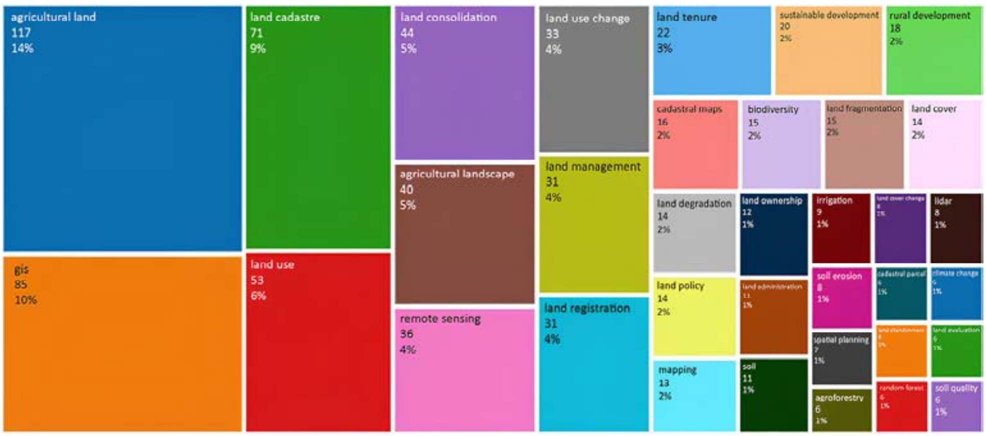

Figure 3: Tree map with 35 main author keywords.

3.2 Synthesis

3.2.1 Qualitative synthesis (MCA)

The multiple correspondence analysis reveals the key relationships and interactions between rural development, agricultural cadastre purpose, the method, spatial unit, policies, geomatic tools, and the countries of the 107 studies related to the field of knowledge. Nearby dots highlight the importance and linkage of the content of the studies (see Fig. 4). MCA identifies three groups:

- **Group 1:** Highlights studies of agricultural land use, environmental land management, product cadastre, land registration, landscape, agricultural suitability, reorganisation, estimation and cadastral evaluation. These studies use the agricultural plot and farm as a spatial unit for agricultural cartography (classification of natural resources), geospatial location of crops, spatial classification/overlay, aerial photointerpretation, photogrammetry and geospatial statistics. Furthermore, these studies highlight the implementation of territorial and agricultural planning policies for rural development.
- **Group 2:** Includes studies on agricultural territory fragmentation, land consolidation, agricultural spatial changes/coverage, crop classification/productivity, property administration and taxes, farming parcel inventory, agricultural irrigation registration and forest management. These studies use the agricultural cadastre and spatial planning to achieve rural development and reorganisation. Agriculture is essential for the rural population and favours rural sectors’ economic, political and environmental development.
- **Group 3:** Highlights the relationship between geomatic tools and agricultural cadastre studies for rural development. GIS (e.g., ArcGIS, ArcView, ArcMap, Corine Land

Cover, and QGIS), RS (e.g., SPOT 4, Ikonos, Sentinel 1-2 and Landsat 7-8), RPAS (drone), and GNSS (GPS) are the tools that achieve rural spatial development through digital maps and spatial analysis. Spatial analysis allows the detection and monitoring of crops, replanning of rural settlements and sustainable development in rural sectors. Furthermore, using geomatics in crop cadastre activities results in greater agricultural productivity in countries such as India, China, and the USA. However, rural countries on the African continent, such as Nigeria and Ethiopia, require more cadastre studies that use technology for sustainable rural development.

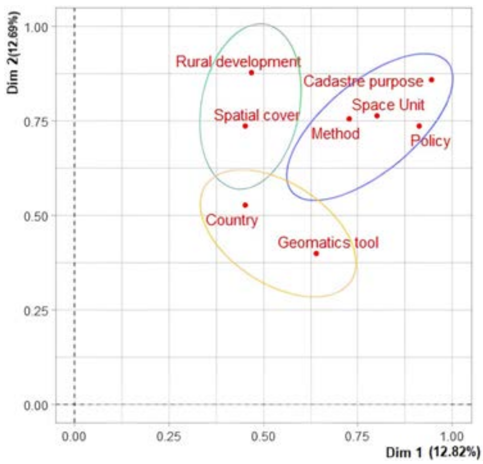

Figure 4: MCA of studies focused on the agricultural cadastre for rural development.

3.2.2 Quantitative synthesis

Fig. 5 presents the quantitative synthesis of the review, which considers the variables method, geomatic tool, spatial unit, spatial coverage, rural development, and cadastre purpose. These variables relate to agricultural cadastre studies and their impact on rural development. The

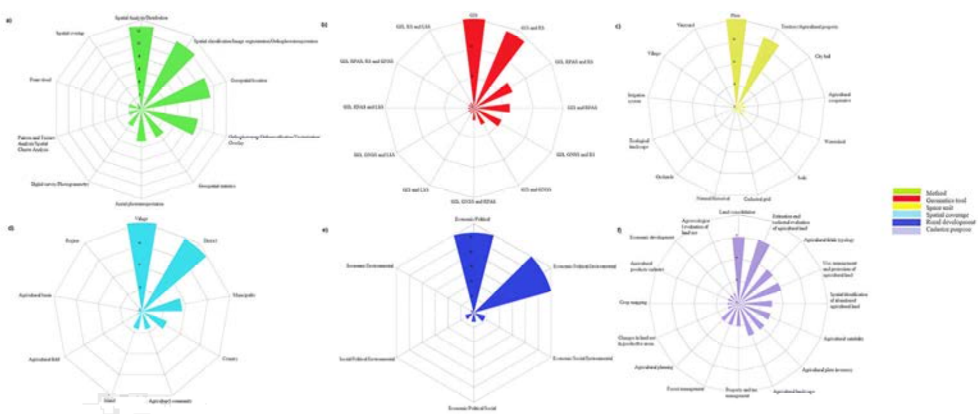

Figure 5: Quantitative synthesis of the review. (a) Method; (b) Geomatics tool; (c) Spatial unit; (d) Spatial coverage; (e) Rural development; and (f) Cadastre purpose.

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quantification considers the scientific contributions of 36 countries, such as China, India, the USA, and the Czech Republic. The predominant methods in studies related to the agricultural cadastre are analysis and spatial distribution, spatial classification/image segmentation/ orthophoto interpretation, and geospatial localisation. A large part of the agricultural cadastre (73.83%) uses GIS, RPAS and RS for agricultural mapping. The predominant spatial unit is the plots, agricultural territories/farms. Furthermore, the relevant spatial coverage of the case study sectors is the villages and districts (58.88%). The agricultural cadastre contributes to land concentration studies, estimation and cadastral evaluation of agricultural lands (21%) for rural sectors' rural economic, political and environmental development (89.72%).

4 DISCUSSION

This review highlights the use of geomatic tools to advance the agricultural cadastre. These tools allow the automation of agricultural processes, which improves decision-making in the agricultural sector and contributes to food security in rural areas. This study found that the fusion of geomatics tools such as GIS, RS, and RPAS with conventional tools such as topographic and cadastral maps provide spatial information related to the agricultural landscape, characterisation of natural resources (agricultural land, watershed), agricultural changes/cover, and land concentration to improve agrarian performance, irrigation, food security, and rural development opportunities (Fig. 3). Furthermore, this spatial information has allowed the development and execution of land use plans, territorial/agricultural reorganisation, land registration, agricultural policies and rural planning.

The analysis identifies that cadastral activity automation through geomatics proposes precise positioning, detection, monitoring and mapping solutions for territorial administration and decision-making. For example, agricultural classification using GIS and GPS to determine farm products number and protect agricultural land [44]; irrigation mapping using RS to estimate irrigated agriculture [45]; and quantification of the spatial variation of soil properties using hyperspectral images obtained from RPAS to predict carbon content in agricultural soils [46].

This study's scientific contribution found advances in agricultural cadastre, which are of greater interest in European and Asian countries due to the economy and extension of agricultural territory. For example, countries such as the Czech Republic, Poland, Slovakia, Spain and Russia base their agricultural classification on crops such as vegetables, sugar beets, aromatic plants, tubers, olives, lemons, grasslands, permanent pastures and forests (Fig. 2). These countries promote the achievement of SDGs 2 and 11 through the general cadastre evolution towards multifunctional integrated systems such as the agricultural cadastre, green cadastre and rural environmental cadastre, which contribute to food security, agrarian property registration, and the value and use of agricultural land [11].

Also, Latin countries show some interest in developing agricultural cadastre. This contribution is related to the lack of implementation of agricultural reforms, the informal market and land tenure insecurity [47]. Furthermore, information on agricultural production systems is scarce and outdated [48]. However, Brazil innovates in digitalisation technology, rural property georeferencing and management to control agricultural territories' conservation issues, land ownership and environmental monitoring [49], [50]. African countries denote a low scientific contribution to the study subject. This low contribution could be associated with it being the only net importing continent of food products. Agriculture is fundamental to the African economy, but agricultural productivity is weak [51]. This event is related to poverty, limited access to inputs/machinery, demographic growth, lack of technology, poor availability of operational information services related to food security, and weakness of national policies. Therefore, in some countries such as

Senegal and Burkina Faso, there is no security of land tenure [52], South Africa faces problems of abandonment of arable communal lands [53], and Uganda faces problems of wetland degradation [54]. However, countries such as Sudan and Ghana focus their classification studies on grain crops such as sorghum, corn, and peanuts with sustainable management practices for agricultural territory [55].

This study finds different developments of agricultural cadastre related to land consolidation in countries such as the Czech Republic and Poland. Through analysis/ distribution and geospatial statistics, they found the effects of changes in land use, landscape structure, and protection of natural resources (Fig. 5) [56], [57]. In countries such as Russia and Spain, cadastral estimation and evaluation of agricultural land through georeferencing, digital cartography and spatial classification allowed soil mapping and valuation of agricultural land [58], [59].

Additionally, this study's review highlights various methodologies used in the planning and operating of the agricultural cadastre. In countries such as Turkey and Russia, spatial geolocation contributes to using and managing land protection in tea cultivation [60]. Likewise, through the point cloud methodology, Slovakia and Spain have identified abandoned agricultural lands spatially to manage natural resources correctly and promote rural development [61], [62]. Similarly, Spain uses aerial photo interpretation to conduct agricultural suitability assessment studies of cereal crops, vineyards and olive trees. All these studies use the agricultural cadastre for their farm management and administration activities that contribute to rural sectors' economic, political and environmental development.

The latest technological advances in agricultural cadastre merge artificial intelligence algorithms, such as supervised machine learning, with logistic regression models for forest use and management [63]. They also fuse digital elevation models (DEM) with measurements through LiDAR to create agricultural LULC maps [64]. Temporal land use and vegetation cover analysis contribute to new rural environmental cadastre policies [65].

Additionally, AI and geomatics technologies, together with human skills, have managed to accelerate cadastral mapping at a global level, detecting and extracting cadastral boundaries through very high-resolution aerial and satellite images that are processed and trained with AI algorithms and geomatics tools on various cadastral topics. For example, precise geographic mapping and surface mapping of cultivated land overlaid on multispectral satellite images along with AI (deep neural network with weather data) improve the accuracy of crop yield prediction [66]. The registry of potential flood zones using AI (neurons as flood conditioning factors) and GIS (training of factor samples) improves the spatial identification of risks or susceptibility to floods in hydrographic basins [67]. Territorial planning and management through AI (automated visual cognition techniques) or object-based very high-resolution image analysis to improve cadastral mapping processes such as the delimitation of rural parcels with exact polygons [68].

5 CONCLUSION

This study identified various developments of agricultural cadastres in land consolidation projects and cadastral estimation/evaluation of agricultural lands (23%); topology/use/ management of agricultural territory (19%); spatial identification of abandoned agricultural land, suitability/inventory of the territory and agricultural landscape (12%). In addition, other less frequent uses contribute to property and tax administration, forest management, agricultural reorganisation and agricultural products cadastre. These studies seek to improve agricultural conditions, increase the profitability of agricultural operations, spatially plan crops, and reorganise rural areas through projects that automate cadastral activities using geomatic tools such as GIS (ArcGIS, QGIS, ArcMap), RS (SPOT, Sentinel 1-2, Ikonos, Landsat 7-8) and RPAS (UAV).

Agricultural landscape analysis, the reality of rural settlements and the use/protection of natural resources through the application of thematic digital maps focus on spatial planning, rural development policies and decision-making in the agricultural management of rural areas. Generally, villages with agricultural fields/farm plots are cadastral spatial units. Therefore, this contributes to the conversion of these areas into potential economic, political, and environmental sectors. In addition, the preservation of natural resources and the sustainable development of agriculture contribute to the ecological tourism development of agricultural fields.

This study does not include documents related to the LAS. However, it could be relevant for developing the agricultural cadastre because it manages tenure, value, land use, and its relationship with society. Also, the data source is limited to two high-quality bibliographic platforms recognised worldwide, without considering databases with other indexes of local or regional impact. In addition, articles in the English language were considered because it is the most predominant language on the topic. Furthermore, the multiple correspondence analysis shows the research gap related to using geomatic tools in the advances of the agricultural cadastre for rural development. Therefore, this study recommends research associated with spatial planning/governance through geomatics for the integrated development of urban and rural areas. Also, research related to promotion and development through AI and geomatics techniques to improve land use care and promote food security.

REFERENCES

[1] Liu, J., Jin, X., Xu, W. & Zhou, Y., Evolution of cultivated land fragmentation and its driving mechanism in rural development: A case study of Jiangsu Province. *J. Rural Stud.*, **91**, pp. 58–72, 2022. https://doi.org/10.1016/j.jrurstud.2022.02.011.

[2] Long, H., Ma, L., Zhang, Y. & Qu, L., Multifunctional rural development in China: Pattern, process and mechanism. *Habitat Int.*, **121**, 102530, 2022. https://doi.org/10.1016/j.habitatint.2022.102530.

[3] Herrera-Franco, G., Sánchez-Arizo, V., Escandón-Panchana, P., Caicedo-Potosí, J., Jaya-Montalvo, M. & Zambrano-Mendoza, J., Analysis of scientific contributions to agricultural development and food security in Ecuador. *International Journal of Design and Nature and Ecodynamics*, **18**, pp. 1129–1139, 2023. https://doi.org/10.18280/ijdne.180514.

[4] Yanbo, Q., Guanghui, J., Wenqiu, M. & Zitong, L., How does the rural settlement transition contribute to shaping sustainable rural development? Evidence from Shandong, China. *J. Rural Stud.*, **82**, pp. 279–293, 2021. https://doi.org/10.1016/j.jrurstud.2021.01.027.

[5] Neumeier, S., Social innovation in rural development: Identifying the key factors of success. *Geogr. J.*, **183**, pp. 34–46, 2017. https://doi.org/10.1111/geoj.12180.

[6] Herrera-Franco, G., Escandón-Panchana, P., Montalván, F.J. & Velastegui-Montoya, A., CLUE-S model based on GIS applied to management strategies of territory with oil wells: Case study – Santa Elena, Ecuador. *Geography and Sustainability*, **3**, pp. 366–378, 2022. https://doi.org/10.1016/j.geosus.2022.11.001.

[7] Banco Mundial, Población Rural, 2024. https://DatosBancomundialOrg/Indicator/SPRURTOTLZS.

[8] Naciones Unidas, Fomento de la agricultura y del desarrollo rural sostenibles, 2024. https://WwwUnOrg/Spanish/Esa/Sustdev/Agenda21/Agenda21spchapter14Htm.

[9] 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 Sens. Appl.*, **20**, 100362, 2020. https://doi.org/10.1016/j.rsase.2020.100362.
[10] Ercan, O., A closer look at Turkish cadastre and its successful completion. *Land Use Policy*, **110**, 104951, 2021. https://doi.org/10.1016/j.landusepol.2020.104951.
[11] Zysk, E. et al., Organizational aspects of the concept of a green cadastre for rural areas. *Land Use Policy*, **91**, 104373, 2020. https://doi.org/10.1016/j.landusepol.2019.104373.
[12] Bacior, S., Austrian cadastre still in use: Example proceedings to determine the legal status of land property in southern Poland. *Land Use Policy*, **131**, 106740, 2023. https://doi.org/10.1016/j.landusepol.2023.106740.
[13] Vučić, N., Mađer, M., Vranić, S. & Roić, M., Initial 3D cadastre registration by cadastral resurvey in the Republic of Croatia. *Land Use Policy*, **98**, 104335, 2020. https://doi.org/10.1016/j.landusepol.2019.104335.
[14] Grant, D., Enemark, S., Zevenbergen, J., Mitchell, D. & McCamley, G., The cadastral triangular model. *Land Use Policy*, **97**, 104758, 2020. https://doi.org/10.1016/j.landusepol.2020.104758.
[15] Kocur-Bera, K., Data compatibility between the land and building cadaster (LBC) and the land parcel identification system (LPIS) in the context of area-based payments: A case study in the Polish region of Warmia and Mazury. Land Use Policy, 80, pp. 370–379, 2019. https://doi.org/10.1016/j.landusepol.2018.09.024.
[16] Scorsino, C. & Debolini, M., A mixed approach for multi-scale assessment of land system dynamics and future scenario development on the Vaucluse Department (Southeastern France). *Land (Basel)*, **9**, 180, 2020. https://doi.org/10.3390/land9060180.
[17] dos Santos, P.P. et al., Geotechnologies applied to analysis of the rural environmental cadastre. *Land Use Policy*, **101**, 105127, 2021. https://doi.org/10.1016/j.landusepol.2020.105127.
[18] Metaferia, M.T., Bennett, R.M., Alemie, B.K. & Koeva, M., The peri-urban cadastre of Addis Ababa: Status, challenges, and fit-for-purpose prospects. *Land Use Policy*, **125**, 106477, 2023. https://doi.org/10.1016/j.landusepol.2022.106477.
[19] Hajji, R., El Asri, H. & Ez-Zriouli, C., Upgrading to 3D cadastre in Morocco: Lessons learned from benchmarking of international 3D cadastral systems. *Land Use Policy*, **128**, 106605, 2023. https://doi.org/10.1016/j.landusepol.2023.106605.
[20] Plaza, J. et al., The Conquense transhumance route in Spain described by 3D geographical information systems, GPS and remote sensing data. *Small Ruminant Research*, **221**:106953, 2023. https://doi.org/10.1016/j.smallrumres.2023.106953.
[21] Escandón-Panchana, P., Herrera-Franco, G., Jaya-Montalvo, M. & Martínez-Cuevas, S., Geomatic tools used in the management of agricultural activities: A systematic review. *Environ. Dev. Sustain.*, 2024. https://doi.org/10.1007/s10668-024-04576-8.
[22] Aydinoglu, A.C. & Bovkir, R., Generic land registry and cadastre data model supporting interoperability based on international standards for Turkey. *Land Use Policy*, **68**, pp. 59–71, 2017. https://doi.org/10.1016/j.landusepol.2017.07.029.
[23] Janus, J., Bożek, P., Mitka, B., Taszakowski, J. & Doroż, A., Long-term forest cover and height changes on abandoned agricultural land: An assessment based on historical stereometric images and airborne laser scanning data. *Ecol. Indic.*, **120**, 106904, 2021. https://doi.org/10.1016/j.ecolind.2020.106904.

[24] Amankulova, K., Farmonov, N., Omonov, K., Abdurakhimova, M. & Mucsi, L., Integrating the Sentinel-1, Sentinel-2 and topographic data into soybean yield modelling using machine learning. *Advances in Space Research*, **73**, pp. 4052–4066, 2024. https://doi.org/10.1016/j.asr.2024.01.040.
[25] Carrión-Mero, P. et al., Water quality from natural sources for sustainable agricultural development strategies: Galapagos, Ecuador. *Water (Basel)*, **16**, 1516, 2024. https://doi.org/10.3390/w16111516.
[26] Salmerón-Manzano, E. & Manzano-Agugliaro, F., Worldwide research trends on land tenure. *Land Use Policy*, **131**, 106727, 2023. https://doi.org/10.1016/j.landusepol.2023.106727.
[27] Tjia, D. & Coetzee, S., Geospatial information needs for informal settlement upgrading: A review. *Habitat Int.*, **122**, 102531, 2022. https://doi.org/10.1016/j.habitatint.2022.102531.
[28] Murmu, S. & Biswas, S., Application of fuzzy logic and neural network in crop classification: A review. *Aquat. Procedia*, **4**, pp. 1203–1210, 2015. https://doi.org/10.1016/j.aqpro.2015.02.153.
[29] Crommelinck, S., Bennett, R., Gerke, M., Nex, F., Yang, M. & Vosselman, G., Review of automatic feature extraction from high-resolution optical sensor data for UAV-based cadastral mapping. *Remote Sens. (Basel)*, **8**, 689, 2016. https://doi.org/10.3390/rs8080689.
[30] Dolejš, M. & Forejt, M., Franziscean cadastre in landscape structure research: A systematic review. *Quaestiones Geographicae*, **38**, pp. 131–144, 2019. https://doi.org/10.2478/quageo-2019-0013.
[31] Munnangi, A.K., Lohani, B. & Misra, S.C., A review of land consolidation in the state of Uttar Pradesh, India: Qualitative approach. *Land Use Policy*, **90**, 104309, 2020. https://doi.org/10.1016/j.landusepol.2019.104309.
[32] Nadan, A., The route from informal peasant landownership to formal tenancy and eviction in Palestine, 1800s–1947. *Contin. Chang.*, **36**, pp. 233–256, 2021. https://doi.org/10.1017/S026841602100014X.
[33] Broadus, R.N., Toward a definition of ‘bibliometrics’. *Scientometrics*, **12**, pp. 373–379, 1987. https://doi.org/10.1007/BF02016680.
[34] Escandón-Panchana, P., Herrera-Franco, G., Martínez Cuevas, S. & Morante-Carballo, F., Prospects of UAVs in agricultural mapping. *Applied Informatics (ICAI 2023) Communications in Computer and Information Science*, **1874**, pp. 309–322, 2024. https://doi.org/10.1007/978-3-031-46813-1_21.
[35] Sánchez, A.D., de la Cruz Del Río Rama, M. & García, J.Á., Bibliometric analysis of publications on wine tourism in the databases Scopus and WoS. *European Research on Management and Business Economics*, **23**, pp. 8–15, 2017. https://doi.org/10.1016/j.iedeen.2016.02.001.
[36] Khan, A., Goodell, J.W., Hassan, M.K. & Paltrinieri, A., A bibliometric review of finance bibliometric papers. *Financ. Res. Lett.*, **47**, 102520, 2022. https://doi.org/10.1016/j.frl.2021.102520.
[37] Muritala, B.A., Sánchez-Rebull, M.-V., Hernández-Lara, A.-B., A bibliometric analysis of online reviews research in tourism and hospitality. *Sustainability*, **12**, 9977, 2020. https://doi.org/10.3390/su12239977.
[38] Audigier, V., Husson, F. & Josse, J., MIMCA: Multiple imputation for categorical variables with multiple correspondence analysis. *Stat. Comput.*, **27**, pp. 501–518, 2017. https://doi.org/10.1007/s11222-016-9635-4.

[39] Carpentier, É., Le paysage rural du Contado d'Orvieto à la fin du XIII ème siècle d'après le cadastre de 1292. *Rev. Nord*, **62**, pp. 177–189, 1980. https://doi.org/10.3406/rnord.1980.3669.

[40] Solle, H., L'utilisation agricole du sol en France. *Acta Geogr*., **45**, pp. 1–25, 1981.

[41] Arslan, F., Değirmenci, H., Rasva, M. & Jürgenson, E., Finding least fragmented holdings with factor analysis and a new methodology: A case study of kargılı land consolidation project from Turkey. *Agronomy Research*, **17**, pp. 683–693, 2019.

[42] Baričević, V. & Šantek, D., Basic topographic database (TTB) data in the preprocess of land consolidation. *Geodetski List*, **73**, 2019.

[43] Kilić, J., Rogulj, K. & Jajac, N., Fuzzy expert system for land valuation in land consolidation processes. *Croatian Operational Research Review*, **10**, pp. 89–103, 2019. https://doi.org/10.17535/crorr.2019.0009.

[44] Yìldiz, O., Coruhlu, Y.E. & Biyik, C., Registration of agricultural areas towards the development of a future Turkish cadastral system. *Land Use Policy*, **78**, pp. 207–218, 2018. https://doi.org/10.1016/j.landusepol.2018.06.041.

[45] Colligan, T., Ketchum, D., Brinkerhoff, D. & Maneta, M., A deep learning approach to mapping irrigation using Landsat: IrrMapper U-Net. *IEEE Transactions on Geoscience and Remote Sensing*, **60**, pp. 1–11, 2022. https://doi.org/10.1109/TGRS.2022.3175635.

[46] Stevens, F., Bogaert, P. & van Wesemael, B., Detecting and quantifying field-related spatial variation of soil organic carbon using mixed-effect models and airborne imagery. *Geoderma*, **259–260**, pp. 93–103, 2015. https://doi.org/10.1016/j.geoderma.2015.05.008.

[47] Ballantyne, B., Bristow, M., Davison, B., Harrington, S. & Khan, K., How can land tenure and cadastral reform succeed? An inter-regional comparison of rural reforms. *Canadian Journal of Development Studies/Revue Canadienne d'études Du Développement*, **21**, pp. 693–723, 2000. https://doi.org/10.1080/02255189.2000.9669909.

[48] Cruz, F., Horcada, A., Castel, J.M. & Mena, Y., Characterization of the cattle production systems in the department of Cundinamarca (Colombia): Proposals for sustainability. *Sustainability*, **15**, 16093, 2023. https://doi.org/10.3390/su152216093.

[49] da Silva, R.F.B. et al., Slow-down of deforestation following a Brazilian forest policy was less effective on private lands than in all conservation areas. *Commun. Earth Environ*., **4**, 111, 2023. https://doi.org/10.1038/s43247-023-00783-9.

[50] Sehn Korting, M., Assumpção e Lima, D. & Sobreiro Filho, J., Brazilian agricultural frontier: Land grabbing, land policy, and conflicts. *IDS Bull*., **54**, 2023. https://doi.org/10.19088/1968-2023.106.

[51] Bégué, A. et al., Remote sensing products and services in support of agricultural public policies in Africa: Overview and challenges. *Front. Sustain. Food Syst*., **4**, 2020. https://doi.org/10.3389/fsufs.2020.00058.

[52] Chinigò, D., The politics of land registration in Ethiopia: Territorialising state power in the rural milieu. *Rev. Afr. Polit. Econ*., **42**, 2015. https://doi.org/10.1080/03056244.2014.928613.

[53] Baiphethi, M.N., Kundhlande, G., Viljoen, M.F. & Manona, S., The potential for land exchange in communal areas to support the adoption of rainwater harvesting practices for crop production: A case study of Thaba Nchu, Free State Province. *Irrigation and Drainage*, **61**, pp. 119–128, 2012. https://doi.org/10.1002/ird.1683.

[54] Obubu, J.P., Mengistou, S., Odong, R., Fetahi, T. & Alamirew, T., Determination of the connectedness of land use, land cover change to water quality status of a shallow lake: A case of Lake Kyoga Basin, Uganda. *Sustainability*, **14**, 372, 2021. https://doi.org/10.3390/su14010372.
[55] Antwi-Agyei, P., Dougill, A.J. & Stringer, L.C., Impacts of land tenure arrangements on the adaptive capacity of marginalized groups: The case of Ghana's Ejura Sekyedumase and Bongo districts. *Land Use Policy*, **49**, pp. 203–212, 2015. https://doi.org/10.1016/j.landusepol.2015.08.007.
[56] Moravcová, J., Koupilová, M., Pavlíček, T., Zemek, F., Kvítek, T. & Pečenka, J., Analysis of land consolidation projects and their impact on land use change, landscape structure, and agricultural land resource protection: Case studies of Pilsen-South and Pilsen-North (Czech Republic). *Landscape and Ecological Engineering*, **13**, pp. 1–13, 2017. https://doi.org/10.1007/s11355-015-0286-y.
[57] Leń, P., An algorithm for selecting groups of factors for prioritization of land consolidation in rural areas. *Comput. Electron. Agric.*, **144**, pp. 216–221, 2018. https://doi.org/10.1016/j.compag.2017.12.014.
[58] Marques-Perez, I., Mora-Navarro, G., Perez-Salas, J.-L., Velilla-Torres, J. & Femenia-Ribera, C., Agricultural land values using geographic information systems: Design location model and tools for information available by geoportal – Application to a Spanish agricultural area. *Survey Review*, **50**, pp. 545–554, 2018. https://doi.org/10.1080/00396265.2017.1350342.
[59] Shapovalov, D.A., Koroleva, P.V., Suleiman, G.A. & Rukhovich, D.I., Soil delineations on public cadaster maps as elements of the soil–land cover mapping. *Eurasian Soil Science*, **52**, pp. 566–583, 2019. https://doi.org/10.1134/S1064229319050119.
[60] Ozcelik, A.E. & Nisanci, R., Land use patterns for driving environmental management of tea agricultural croplands. *Comput. Electron. Agric.*, **122**, pp. 41–54, 2016. https://doi.org/10.1016/j.compag.2016.01.013.
[61] Sačkov, I., Barka, I. & Bucha, T., Mapping aboveground woody biomass on abandoned agricultural land based on airborne laser scanning data. *Remote Sens. (Basel)*, **12**, 4189, 2020. https://doi.org/10.3390/rs12244189.
[62] Heider, K., Rodriguez Lopez, J.M., Balbo, A.L. & Scheffran, J., The state of agricultural landscapes in the Mediterranean: Smallholder agriculture and land abandonment in terraced landscapes of the Ricote Valley, southeast Spain. *Reg. Environ. Change*, **21**, 23, 2021. https://doi.org/10.1007/s10113-020-01739-x.
[63] Szabó, P., Diniz, É.S. & Houška, J., Traditional agroforestry on forested land: A comprehensive analysis of its distribution pattern in the 19th century. *Agroforestry Systems*, **98**, pp. 115–127, 2024. https://doi.org/10.1007/s10457-023-00894-4.
[64] Bucała-Hrabia, A., Reflections on land use and land cover change under different socio-economic regimes in the Polish Western Carpathians. *Reg. Environ. Change*, **24**, 28, 2024. https://doi.org/10.1007/s10113-024-02187-7.
[65] Da Silva, J.L.A., Ribeiro, V. de O., Diodato, J.O. & Corrêa, N.F., Brazilian forest code as an instrument for environmental conservation: Case study of the Curupaí and Engano watersheds, Mato Grosso do Sul/Brazil. *Revista de Gestão Social e Ambiental*, **18**, e04484, 2023. https://doi.org/10.24857/rgsa.v18n3-024.
[66] Engen, M., Sandø, E., Sjølander, B.L.O., Arenberg, S., Gupta, R. & Goodwin, M., Farm-scale crop yield prediction from multi-temporal data using deep hybrid neural networks. *Agronomy*, **11**, 2576, 2021. https://doi.org/10.3390/agronomy11122576.

[67] Costache, R. & Tien Bui, D., Spatial prediction of flood potential using new ensembles of bivariate statistics and artificial intelligence: A case study at the Putna river catchment of Romania. *Science of The Total Environment*, **691**, pp. 1098–1118, 2019. https://doi.org/10.1016/j.scitotenv.2019.07.197.
[68] Nyandwi, E., Koeva, M., Kohli, D. & Bennett, R., Comparing human versus machine-driven cadastral boundary feature extraction. *Remote Sens. (Basel)*, **11**, 1662, 2019. https://doi.org/10.3390/rs11141662.