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Land use maps: insights from the Polish experience

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Abstract. This study explores thematic and methodological trends in land use and land cover (LU/LC) mapping in Poland within the broader context of land system science.
In the current era of global environmental change, maps that depict land use have increasingly become essential. Understanding spatial patterns is vital for sustainable land governance, which in turn underpins a range of policy and development goals. Based on 272 JCR-indexed publications, the study identifies dominant research themes and methodological approaches. Polish scholars have primarily focused on LU/LC classification, modelling, and temporal dynamics, with remote sensing and GIS being central. A knowledge map of Polish land use research is presented, highlighting key networks and authors.

Key words:
land science,
land use mapping,
systematic review,
LU/LC,
land changes,
research trends,
Poland

Introduction

Land system science integrates social, ecological and economic aspects to address land use change to better understand and manage land systems for sustainability. Over time, land system science has evolved from focusing primarily on mapping land cover changes to analysing the complex interactions between human decision-making and environmental dynamics. In this context, land use mapping and land use maps are crucial, not only for detecting visible land cover changes but also for identifying more subtle shifts in land management intensity and socio-economic functions (Rounsevell et al. 2012). Amid accelerating environmental changes, the importance of land use maps has grown substantially. As scaled representations of the Earth's surface, such maps enable comprehensive spatial analysis, especially for complex structures like land use systems (Cihlar and Jansen 2001). The effectiveness of cartographic visualisation depends on multiple interrelated factors, including scale and generalisation, map type, data quality and intended audience (Slocum et al. 2008; Andruszkiewicz et al. 2020). In addition, map purpose and users influence the need for interpretation aids (Słomska-Przech and Gołębiowska 2021).

Land use mapping began over a century ago. In 1916, American geographers initiated a research tradition aimed at classifying and visualising land use effectively (Ciołkosz 2011). These efforts continue today across many countries, driven by growing awareness of the role of land in sustainability. Scholars increasingly emphasise the need to integrate empirical land use data and mapping techniques into

multi-scale models to better understand feedback between local land use and global change. Land use and land cover (LU/LC) maps are vital tools for capturing spatial dynamics and identifying teleconnections between distant regions by mapping both physical landscapes and socio-economic drivers of change. However, as Cihlar and Jansen (2001) and Malczewski (2004) observe, comprehensive methodological frameworks for producing accurate and context-sensitive land use maps remain underdeveloped and are applied unevenly. Moreover, Winther (2022) stresses that mapping is not a neutral scientific process, while Turner et al. (2021) highlight that land use maps often reflect implicit values and priorities. Mapping choices can thus influence which interests and trade-offs are represented in land use policy and planning.

The Polish experience in land use mapping reflects a century-long evolution shaped by scientific ambition, technological progress and institutional constraints. The origins of systematic land use cartography in Poland can be traced to 1916, when Eugeniusz Romer published the first map explicitly titled "Land Use" in the Geographical-Statistical Atlas of Poland (Romer 1916). This pioneering effort laid the groundwork for subsequent cartographic developments, particularly during the interwar period. Dukaczewski and Bielecka (2018) note that Włodzimierz Kubijowicz, Edward Rühle and Stanisław Leszczycki produced regional land use maps, primarily based on topographic sources. Nonetheless, these early maps were limited in thematic scope, emphasising agricultural and forested areas while largely omitting urban and infrastructural features. Following World War II, the Polish Head Office of Surveying and Mapping launched ambitious initiatives to create large-scale economic maps that included land use components. Despite initial enthusiasm, these efforts were ultimately hindered by technical limitations and organisational challenges, leading to the abandonment of nationwide mapping objectives (Ciołkosz and Kozak 2009). Concurrently, academic geographers, most notably Dziewoński and Kostrowicki (1956), advanced the field by developing detailed land use classification systems and conducting field-based mapping campaigns. These efforts culminated in a comprehensive methodology that gained international recognition. However, the high cost and operational complexity of such detailed mapping precluded the realisation of full national coverage. Uhorczak (1969) argued that a land use map of Poland could be produced relatively quickly through desk research alone. "Poland's general land utilization map" was conceived as a series of maps illustrating the five main land use types (water, meadows and pastures, forests, arable land, and settlements). Uhorczak considered the map's level of detail, which corresponded to a scale of 1:100,000, to be its most important feature. The map received particular attention after being displayed at a cartography exhibition held for the 18th International Geographical Congress in Rio de Janeiro (Kostrowicki 1960).

A major turning point was reached in the 1970s with the advent of remote sensing. The launch of Landsat in 1972 ushered in a new era of land use mapping, enabling broader spatial coverage and more frequent data updates. The Institute of Geodesy and Cartography in Warsaw emerged as a national leader in this domain, producing Poland's first satellite-based land use map in 1980 and contributing to a series of national and regional atlases. The integration of satellite imagery with topographic data enabled more nuanced representations of land cover and use, although early spatial resolution limitations constrained the level of detail (Ciołkosz and Kozak 2009). During the 1990s and 2000s, Poland actively participated in European land monitoring initiatives, most notably the CORINE Land Cover (CLC) programme, which provided standardised and comparable land cover data across the continent. Polish institutions were also involved in projects such as LUCAS and INSPIRE, further embedding national land use mapping within broader international frameworks.

This article aims to situate Polish research on LU/LC maps and mapping methodologies within the broader context of land system science and sustainable land management challenges. It provides in-depth insight into the field of study in question. Through a systematic review of publications indexed in the Web of Science Journal Citation Reports (WoS JCR) over the past three decades, this study first seeks to portray the intellectual foundations, thematic trends and research frontiers of LU/LC mapping in Poland. Second, it aims to examine Poland's position within the global scientific landscape of LU/LC research. Third, it reaffirms the importance of land use maps in addressing contemporary sustainability challenges and reflects on the biblical directive to "fill the Earth and subdue it" (Genesis 1:28) in the context of responsible environmental stew-

ardship. The findings provide a basis for discussion about future LU/LC mapping challenges in the context of integrated and interdisciplinary approaches.

Research materials and methods

Literature review plays an essential role in academic research by consolidating existing knowledge and evaluating the current state of a field. It is instrumental in identifying research gaps, shaping questions for future studies, and situating new contributions within an established body of work. In the realm of land use maps and mapping, several bibliographic reviews have addressed this subject from different perspectives. Van Vliet et al. (2015) published broad meta-studies in land use science by analysing current coverage and prospects. Simensen et al. (2021) focused on landscape mapping. Meanwhile, Biłozor and Cieślak (2021) examined urbanisation dynamics, and Biczkowski et al. (2024) addressed the afforestation of infertile agricultural land. Contribution to land use change modelling was made by Bielecka (2020), and reviews of ecosystem services have been presented by Hanaček and Rodríguez-Labajos (2018). Additionally, the exploitation of CORINE data was discussed by Bielecka and Jenerowicz (2019). The scope and approach of review papers vary not only in thematic and geographic focus but also in methodological framework.

This study uses a method that combines a rigorous search strategy with critical synthesis. It combines the breadth of a comprehensive review with the evaluative depth of critical analysis, ultimately producing what is known as a "best evidence synthesis". Citation and co-citation analysis and bibliographic coupling were employed to examine the scientific contributions of Polish researchers in the field of land use mapping. Citations acknowledge previous research by referencing the pioneers and intellectual foundations of the field. At the same time, they reveal emerging research trends by referencing the most recent work. Papers that are frequently cited are often considered to be "hot spots". Co-citation, which highlights how often two papers are cited together in other research documents, is an effective indicator of emerging scientific topics. The strength of co-citation between two documents indicates their semantic relatedness. It is expressed by the strength coefficient (s_{ij}) described in depth by Callon et al. (1991). Bibliographic coupling occurs when two works cite the same third work in their bibliographies, indicating that the two works may cover similar subject matter. As Bielecka (2020) notes, co-citation offers a forward-looking perspective by highlighting emerging research topics, whereas bibliographic coupling is mainly retrospective, providing information about most-cited authors or those who laid the foundations for the research in question.

The analysis covers an overview of diachronic publication output and citation analysis, as well as screening publication records to identify: the most frequently cited papers and prominent authors, cooperation network, vital research topics, and problems that remain unresolved in LU/LC mapping studies (analysis of citations, co-citations and bibliographical coupling, keywords clustering). The Web of Science (WoS) was chosen as the main data source due to its multidisciplinary nature and its guarantee of high-quality, indexed research publications (Bar-Ilan 2010). A search was conducted on June 4th, 2025, using the general search interface with the terms "land use map", "land cover map", and "Poland", combined using the Boolean operators AND and OR (Table 1). The search yielded a total of 272 papers.

The research performance of Polish publications indexed in the WoS on LU/LC was evaluated using VOSviewer, InCites (Clarivate Analytics platform) and Excel.

Table 1. Data search criteria

No.	Criterion	Description
1	Terms	Topic: "Land use map" AND "Poland OR "land cover map" AND "Poland
2	Time frame	1900–4.07.2025
3	Language	English
4	Document types	Article, proceedings papers, book chapters
5	WoS categories	Natural sciences

Research results

Quantitative analysis of the Polish scientific output

Over the last nearly three decades (1996–2025), 272 documents, including 235 articles, 35 proceedings papers and two book chapters were published and cited 5,779 times (Fig. 1). The exponential model of citations suggests that each subsequent year builds significantly on the previous ones. This is the essence of citation momentum. Until 2013, the annual publication output did not exceed ten articles, with a maximum of 25 articles being published in 2014, when Poland benefited significantly from *EU Cohesion Policy* funds. Furthermore, around 2014, there was a surge in the use of GIS and satellite imagery (e.g., Sentinel and Landsat missions). This made land use mapping more accessible and accurate. Finally, there was an increased emphasis on urban planning, environmental protection and agricultural monitoring, all of which rely heavily on land use maps and data.

A total of 713 researchers from 36 countries published 272 documents across 59 journals and five conference proceedings. The numbers of documents and citations are highly diverse, as indicated by the Pearson's coefficient of variation of 1.11 and 2.05, correspondingly. *Remote Sensing* (MDPI, Basel) tops the list with 14 published research papers that have been cited 209 times. Other MDPI journals (*Sustainability, Land*) also feature highly. Of the six Polish journals, *Sylwan* (ten articles, 34 citations) has the highest number of articles, follow by *Quaestiones Geographicae* (five documents, 33 citations) and *Geographia Polonica* (5 articles, 28 citations). Only two academics (both from Jagiellonian University) published more than ten papers in this field: Jacek Kozak with 11 papers cited 464 times; Dominik Kaim with 12 papers cited 247 times. Nine other authors published at least five papers. The two most frequently cited papers (Kozak 2003; Kozak et al. 2007) examine changes in the use of forested land in the Western Carpathians over the past two centuries. Table 2 shows the five most productive authors in this field. It is worth noting that some authors who published seven articles were omitted due to their relatively low numbers of citations.

Personal and institutional cooperation

Most researchers collaborate primarily within their own university or institute, forming relatively narrow networks. Only a minority engage in broader collaborations across universities, and even fewer maintain international partnerships. Wider collaborations typically emerge through structured research projects. The Polish Academy of Sciences (PAN) stands out as a leader in this domain, as shown in the collaboration network (Fig. 2). PAN maintains joint research efforts, including land use mapping, with 14 universities worldwide, including the University of Wisconsin (USA) and Humboldt Universi-

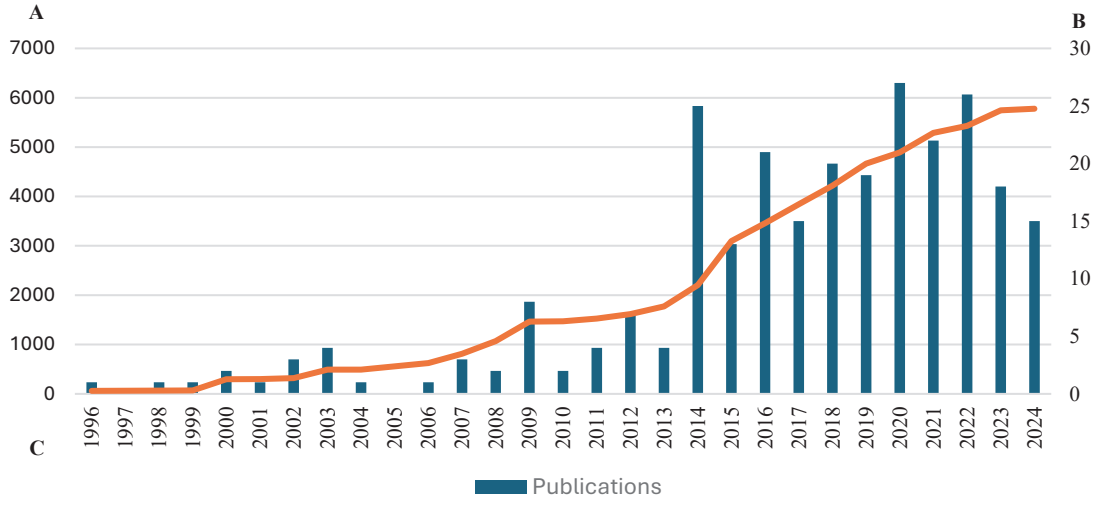

Fig. 1. Publication output by the end of 2024
Explanation: A – cumulative citation, B – publication by year, C – year, red line – cumulative citation, blue bars – yearly number of WoS documents

Table 2. Most-productive authors on LC/LC maps and mapping covering Poland territory, ordered by document numbers

Author	Organisation / country	Web of Science documents	Total citation number	Total link strength (s_{ji})	Research interests
Kaim, Dominik	Jagiellonian University, Poland	12	247	55	Forest – land use changes, mapping, historical reconstructions, Carpathians
Kozak, Jacek	Jagiellonian University, Poland	11	464	40	Forest mapping – land use mapping and analysis, remote sensing, Polish Carpathians
Radeloff, Volker C	University of Wisconsin Madison, USA	9	830	33	Agriculture land use, remote sensing
Ostafin, Krzysztof	Jagiellonian University, Poland	8	205	50	Historical maps of forest, long term land use changes,
Kuemmerle, Tobias	Humboldt University of Berlin, Germany	7	974	23	Land use changes mapping and modelling, remote sensing,

ty of Berlin (Germany). The Jagiellonian University follows, actively collaborating with seven research institutions, including PAN.

International cooperation in land use mapping remains limited, with most countries engaging in bilateral or regional partnerships. Broader, multi-country collaborations are relatively rare and typically emerge through structured research initiatives, in which Poland often acts as a hub for international cooperation. More than ten documents are the products of research cooperation in land use mapping between Poland and Germany (21 documents, sij=21), USA (13 documents, sij=22). These partnerships reflect Poland's importance in advancing land use mapping methodologies and fostering cross-border research integration.

The correspondences in the thematic scope of LU/LC in Poland studies are underlined by the bibliographic coupling of authors (Fig. 3), which assumes that the more references two authors have in common in their oeuvres, the more similar their research is. Three groups of researchers are distinguished among those that published five or more papers and were cited at least ten times each.

The red cluster led by D. Kaim and J. Kozak from Jagiellonian University comprises study on Carpathian forested landscape mapping and its dynamics, diversity and fragmentation over the last 200 years (Kozak 2003; Kaim et al. 2016). International cooperation is also clearly visible. The two remaining cluster are very small, counting only two academics. The green cluster relates to mapping both land use and land-use changes (e.g., Bielecka 2020), while the blue one pertains to remote sensing for green area reclamation (e.g., Szostak et al. 2014).

Research trends and frontiers: co-word analysis

Keywords – the words or phrases that summarise the content of a paper – are vital for making research more discoverable and visible online. Of the 272 WoS research documents on land use maps over Polish territory, 1,606 keywords were used, 33 of which appeared ten or more times. "Land use" and "Poland" clearly dominate, having been used 44 times and being strongly linked (sij=31 and sij=30, respectively) and with high co-occurrence (sij=133, sij=105). The thematic scope of the research represented by the keywords centres on the complex interactions between land use change, vegetation dynamics and landscape transformation, particularly in the con-

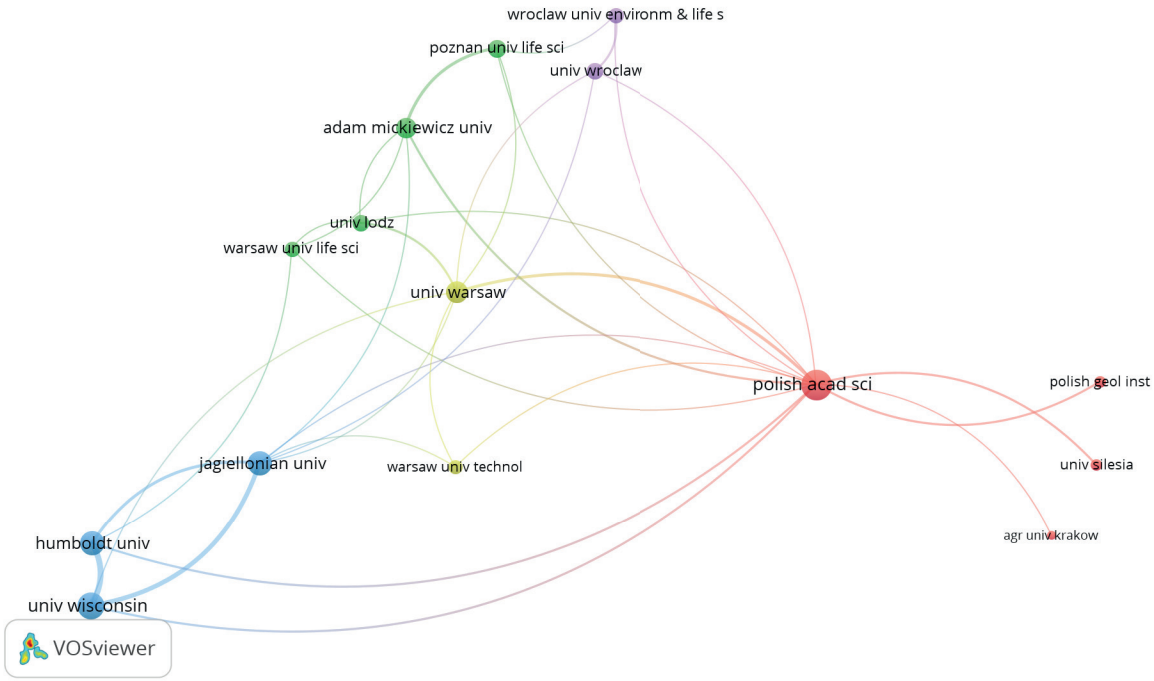

Fig. 2. Patterns of research collaboration in the field of land use mapping and maps (University of Agriculture in Krakow, Humboldt University, Jagiellonian University, Marie Curie Sklodowska University, Military University of Technology, Polish Academy of Sciences, Polish Geological Institute, Poznan University of Life Sciences, University of Lodz, University of Silesia, University Warmia & Mazury, Warsaw University, University of Wisconsin, Wroclaw University, Warsaw University of Life Sciences, Warsaw University of Technology, Wroclaw University Environment & Life Sciences)

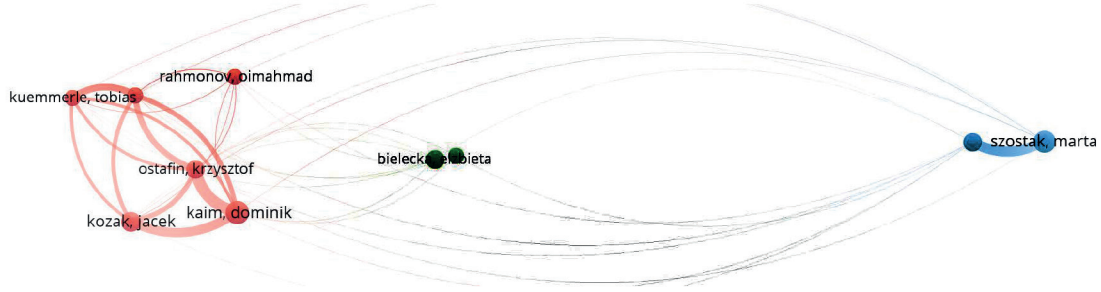

Fig. 3. Authors who published five or more papers – bibliographic coupling

text of Central and Eastern Europe, with a strong focus on Poland and the Carpathian region. Figure 4 highlights clusters of interconnected research terms, suggesting a multidisciplinary approach that integrates remote sensing, GIS, historical cartography and ecological modelling. Current research trends emphasise the abandonment of agricultural land and its cascading effects on biodiversity, forest regeneration and soil erosion. The use of airborne laser scanning and remote sensing technologies is prominent, enabling detailed classification and mapping of land cover and vegetation changes over time. Historical maps and spatial models are increasingly used to understand long-term landscape dynamics and to identify the drivers behind land use transitions, such as socio-economic shifts, policy changes and environmental pressures. Emerging frontiers in this field include the restoration and conservation of abandoned farmland, the development of predictive models for land use change, and the integration of

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biodiversity metrics into land management strategies. There is also growing interest in understanding how patterns of land abandonment influence ecosystem services and how these patterns vary across different regions of Europe. The research is inherently spatial and temporal, relying heavily on geospatial technologies to analyse and visualise changes in land cover and to inform sustainable landscape management practices.

The green cluster (10 words) revolves around environmental transformations, particularly in forested landscapes such as the Carpathians. It emphasises the study of land use and land cover change, identifying the drivers behind these shifts, whether natural or anthropogenic. This cluster is deeply rooted in understanding forest dynamics and the broader ecological consequences of changing land patterns. The red cluster (13 items) centres on agricultural land, with a strong focus on farmland abandonment and restoration across Europe. It explores the spatial and temporal dimensions of land abandonment, its causes, and the potential for ecological recovery. This cluster often overlaps with regional studies examining how different European areas are affected by and respond to agricultural decline and land-use transitions. The blue one (5 words) is methodologically oriented, highlighting the use of GIS and classification techniques to analyse biodiversity and land use. It provides the technical backbone of the research, providing tools and frameworks for mapping, modelling and assessing ecological variables. It is essential for translating raw spatial data into meaningful insights about landscape structure and biological diversity. The yellow cluster (5 words) focuses on conservation and management strategies, assessing their environmental impacts, especially in relation to soil erosion and landscape dynamics. It deals with practical applications of ecological knowledge, aiming to mitigate degradation and promote sustainable land use. The cluster connects scientific understanding with policy and land stewardship, emphasising the importance of informed decision-making in environmental management.

Discussion

Semantics, issues and concerns

An effective analysis of human environmental impact requires a focus on two fundamental aspects of land cover and land use. Despite this dual focus, there is considerable inconsistency in how these terms are interpreted and applied across research.

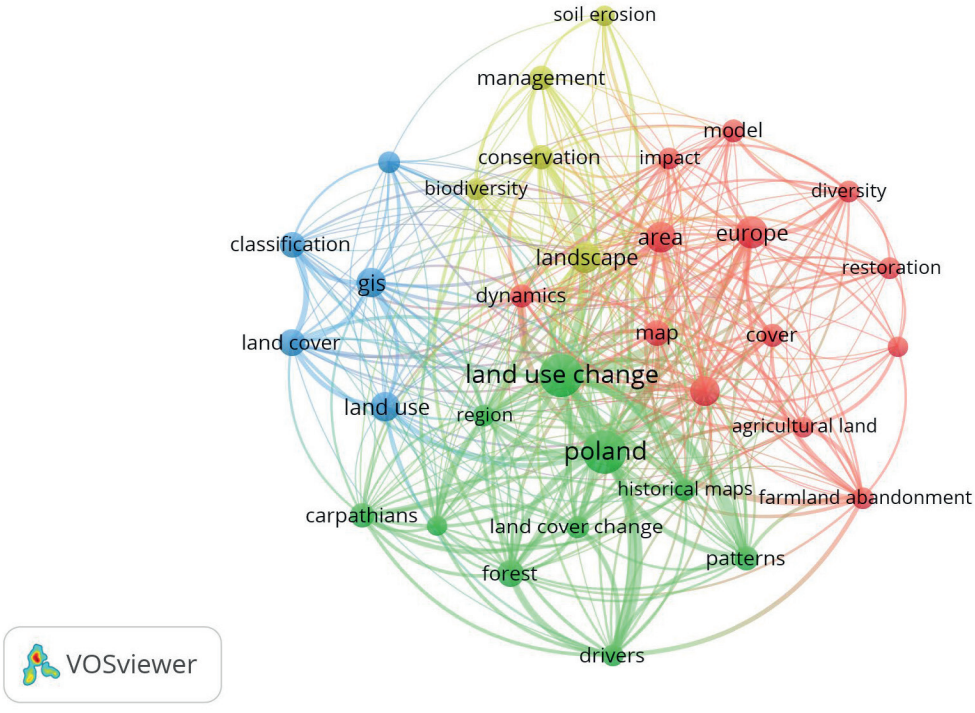

Fig. 4. Keywords co-occurrence

Some studies treat land cover and land use as separate entities; others merge land cover data into land use categories (Jankowski 1972). The term "land cover" typically refers to the physical, bio-physical characteristics of the Earth's surface like vegetation, water, soil and artificial structures, whereas "land use" denotes the functional, socio-economic purpose of a given area, such as residential, industrial or agricultural use (Kostrowicki 1960). One major issue highlighted in the literature is the difficulty in clearly distinguishing between land cover and land use. Functional use can often be inferred from physical characteristics and vice versa (Nunnally and Witmer 1972). However, the relationships are not always straightforward; similar land cover types like "grass" can correspond to a wide variety of land uses (lawns, airport runways, pastures, golf courses) while a single land use type like "residential area" might encompass diverse land cover elements such as buildings, trees and bare soil. The overlap and blending of these categories are evident in mapping practices (Bielecka and Jenerowicz 2019). This inconsistency suggests that separating land cover from land use is not always justifiable or methodologically sound, particularly when both perspectives are required for environmental assessments. Therefore, a pragmatic approach is recommended, where both land cover and land use are integrated in analysis and mapping efforts to enable better understanding and monitoring of environmental changes at national, regional and local levels. As Stamp (1948) articulated, land use should be understood as the spatial representation of surface forms – used or unused – emphasising both their interrelation and the often superordinate role of land use in environmental interpretations. This integrated perspective is essential for assessing the complex interactions between human activities and natural systems. It is also worth mentioning that scholars and organisations have highlighted the persistent lack of accessible, standardised methods for practical land use mapping (Göritz et al. 2018; Kate et al. 2022).

Land use science of "fill the Earth and subdue it"

The biblical directive to "subdue the earth" (Genesis 1:28) can be constructively interpreted in the context of modern land use mapping as a call for the organised, ethical and sustainable management of land resources. In the context of land use mapping, this theological mandate aligns with the systematic observation, classification and management of land for human benefit. Land use mapping itself can be seen as a contemporary method of "subduing" or organising the Earth to manage agriculture, urbanisation, conservation and other needs. Historically, interpretations of Genesis 1:28 have sometimes been linked to exploitative attitudes toward nature. White (1967) critiqued such readings, arguing that the dominion mandate has often been misused to justify environmental degradation. Scholars now advocate for a stewardship-based interpretation of "subdue the earth", emphasising care, responsibility and ecological limits. This perspective is reflected in sustainable land use mapping approaches that incorporate land suitability analysis and environmental protection alongside development. Campbell highlights that remote sensing supports this ethical shift by providing the means to detect ecological stress and plan accordingly "Remote sensing provides critical information for identifying areas vulnerable to environmental degradation, ensuring that land management decisions are ecologically sound" (Campbell 2011).

Land use mapping inherently involves observation, classification and documentation of the Earth's surface for various human purposes, including agriculture, urbanisation, conservation and infrastructure development. This activity directly connects with the biblical concept of "subduing the earth" through the systematic organisation of space and rational planning (Bryant 2005). Thus, the process of mapping land for various uses can be seen as an act of fulfilling the Genesis mandate bringing the Earth under organised human care and direction. The emergence of remote sensing and GIS technologies has expanded the scope of land use mapping, allowing for unprecedented precision and scale in monitoring land cover changes and assessing resource distribution. In this technological context, "subdue the earth" is no longer solely about physical cultivation, but also involves digital observation and responsible decision-making over the land. Such a technological perspective aligns with the biblical directive of stewardship, positioning mapping technologies as modern instruments through which humans responsibly exercise dominion.

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Study limitations

Valuable research documents published in national journals in the 1960s and 1970s are not included in publications indexed in the WoS Core Collection. As discussed in Section 1, land use maps were the subject of widespread discussion among geographers and cartographers around the world during this period. Additionally, most conference proceedings, particularly national ones, are excluded from the WoS database. Consequently, the contributions of influential figures to the creation of land use maps in Poland, such as Prof. Ciołkosz (IGiK) and Prof. Kostrowicki (PAN), are only mentioned in the preface. One possible solution would be to analyse publications in Google Scholar, but this has been dismissed due to criticism of the use this database for bibliometric analyses (Bar-Ilan 2010). Another limitation lies with the WoS search engine, which adds all forms of the searchable keyword to a given query. For example, "map" was expanded to "mapping". Additionally, the reliance on WoS-indexed publications could introduce a language bias, as many valuable studies published in Polish or other languages are excluded. Future studies could benefit from incorporating multiple databases to capture a broader view of the field.

Conclusions

Land use maps in Poland serve as essential tools within land system science, enabling the integration of spatial data with socio-economic and ecological models to better understand and manage land transformations under global environmental pressures. The evolution of Polish land use mapping, from early topographic representations to advanced remote sensing techniques, illustrates how land system science has increasingly emphasised interdisciplinary approaches to capture the complexity of human–environment interactions. Maps play a crucial role in visualising spatial patterns and relationships, serving as key tools for translating complex data into accessible formats. Recent research in this field is marked by a strong interdisciplinary and multi-thematic character, with a dominant focus on technological advancements in GIS and remote sensing. Studies often explore land use change driven by factors like urbanisation, agricultural abandonment, and deforestation, reflecting broader socio-economic and environmental pressures. Much of this work centres on Poland and Europe, frequently utilising CORINE data to support regional analyses. An ecological perspective is also evident, linking land use mapping to issues such as habitat fragmentation, conservation and ecosystem services. Additionally, there is growing interest in temporal dynamics, with researchers increasingly employing time-series and change-detection methods to understand transitions over time. These trends highlight the need for continued investment in geospatial technologies, greater integration of socio-economic data to enhance policy relevance, and stronger international collaboration to standardise methodologies and improve data comparability across regions.

Disclosure statement

No potential conflict of interest was reported by the authors.

Author contributions

Study design: EB; data collection: EB; statistical analysis: EB, DD; manuscript preparation: EB, DD; literature review: EB, DD.

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