A systematic literature review of the potential use of remote sensing materials in teaching school geography

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Abstract. In school geography teaching, remote sensing (RS) materials play a very important role as an essential element of scientific education in integrating the main components of the Earth system. However, despite the demand for the use of RS materials in school geography teaching, their use remains low. Therefore, the aim of this study was to conduct a systematic review of the literature on the possibilities of using remote sensing data in school geography teaching. In this study, we analysed articles published in scientific journals indexed in the Web of Science, Scopus and PubMed databases using the PRISMA method. The results showed that out of the 25 articles selected, 32% were creative and motivational, while 24% focused on explaining the benefits of remote sensing materials in geography education. In addition, it was found that 6 articles were written using a combined research method (24%), 4 articles using qualitative data analysis methods (16%), and 4 articles using semantic network analysis (16%). In terms of quantity, 2020 (20%) was identified as the year in which the largest number of articles were published. 16% of authors published their research in the journal Remote Sensing. Thus, we have identified the positive experience of Western European countries such as Germany, the United Kingdom, Greece, Spain, and Portugal in using remote sensing materials in teaching geography in schools. This study aims to contribute to the literature by substantiating the effectiveness of using remote sensing materials in improving the geospatial cognitive abilities of schoolchildren.

Keywords: teaching school geography, remote sensing, potential use of materials, systematic literature review.

Introduction

Remote Sensing (RS) has recently become a key methodology in geography education, in that it allows students to interact with real-life images of the Earth surface and to learn more about geographical features and processes [1]. Another turning point in the history of the remote sensing came in 1993 with the creation of the Remote Sensing Core Curriculum, which was intended not only to standardize the application of the RS resources within the college ranks but also to make the education of geography superior both in the country and on a global scale [2]. RS has grown much broader than this original focus and it emerged as an interdisciplinary science that combined characteristics of geography, biology, physics, mathematics and computer science, thus

finding itself on the border between natural science and social sciences [3]. Regarding geography education, RS provides not only creative and realistic teaching resources, but also a variety of forms of spatial information presentation, starting with visual images and ending with interactive online tools [4]. In this way, RS offers a critical spatial foundation inquiry-based science learning and teaches students to think in systems that allow them to combine the basic elements of the Earth system in learning [5]. However, in spite of its proved potential, the use of RS is under-explored in geography in school. One of the key obstacles to its broader use is the low access to pedagogically modified aerospace photographs and educational materials that are of didactic quality. Although there has been an increase in the prevalence of satellite imagery and even the introduction of satellite receipts into the curriculum of some countries, the reality of the actual application of satellite imagery in classrooms remains erratic and in many cases relies on the initiative or availability of outside programs. This lack of engagement between the increasing technological potentials of RS and its small infiltration into the daily practice of teaching is a major gap in the literature of RS and in education. To fill this gap, it is necessary to conduct systematic research and to consider the way RS can be successfully implemented in instruction that would enhance student learning outcomes. Beyond its technological potential, RS must also be positioned within broader educational policies and curriculum frameworks. Many modern curricula emphasize STEM competences, sustainability education, and digital literacy, which align directly with the capabilities of RS. For example, in Germany, RS integration has been linked with interdisciplinary STEM subjects, while in Greece RS has been highlighted in the context of climate change education [6]. Embedding RS within such policy frameworks reinforces its relevance and ensures that the technology is not viewed as an isolated innovation but as part of systemic curriculum reform.

Curriculum development is presently given new opportunities by the advances in RS technology. Staffing regional geography training with RS not only improves the level of content knowledge but also promotes competence-based education that motivates students to think through inquiry, finding solutions and providing evidence-based arguments [7]. The efficient application of RS to schools is more than simple showing of satellite images; it is the pedagogical activities that involve introduction of RS concepts, satellite data collection and analysis, thematic maps creation, field study and data reliability assessment [8]. Besides, interactive and interdisciplinary modules become available, which offers the opportunity to develop methodological, media, and geospatial competences of students, as well as critical thinking and self-directed learning skills [9]. All these advantages indicate the necessity of revising the approach towards the teaching of geography and of adapting it to the current technological and scientific trends. Continuing this discussion, the current study has a definite aim: to critically examine the possibilities of RS materials in enhancing geographical literacy of students in the framework of systematic review of the literature. Through research in that has been indexed in major international databases this study will not only be descriptive but also be critical in its synthesis of how RS has been incorporated into geography instruction, where it has been successfully developed and where steps have yet to be taken. That way, the study fills the above research gap directly between the accessibility of RS technologies on one hand and their unequal utilization in classroom practice on the other. The importance of such an aim is the further revolution of the field of geography in general. The fast development of geo-information technologies and their growing use in education is changing the manner in which scientific knowledge is provided, and presents new opportunities of integrating science, technology and pedagogy even more closely [10]. However, even with these possibilities there is an unequal translation of RS applications into practical resources of school-level instruction. Such discrepancy implies a severe necessity of critical analysis and methodological transition.

It is too, necessary to place RS in its broader societal effect. The technology has already changed various industries such as agri-

culture, management of natural resources, transportation and environmental surveillance proving its flexibility and applicability [11]. These practical uses can be effectively used strategically in learning institutions to bridge the gap between learning in the classroom and the global issues like sustainability, climate change and resource management. An RS imagery, formed in the complex of the high-end hardware and software systems and integrated with the information provided by the vector maps, provides the essentially comprehensive vision of the atmosphere, lithosphere, hydrosphere, and biosphere of the Earth [12]. However, the didactic modification of these sophisticated data items is not developed enough to support the distinction between the scientific innovations and the classroom activities.

Considering this, this paper determines that RS is not only complementary, but the major transformer of the teaching of geography in schools. Conventional atlases and textbooks tend to give inert and generalized images of the geographical phenomena, whereas RS has the potential to present dynamic, high-resolution, and context specific information. This change is the foundation of the main hypothesis of the study: the appearance of the RS materials into the geography teaching process may result in the significant increase of the visibility of the learning process, its effectiveness, and its relevance. Simultaneously it presents geography as a new, scientifically based field that is on the one hand actively involved in the current global affairs and on the other hand making students ready to meet the challenges of the 21 st century world.

The current research is based on the notion of geospatial literacy that focuses on the performance of students in terms of comprehending, interpreting, and using the spatial information to resolve the real-life issues. RS can be directly used to develop this competence as it delivers real data and imagery, which can be viewed as a rich source of geography education. Meanwhile, the process of RS integration is consistent with the approaches of competence-based and inquiry-oriented learning that promote the independent exploration, critical analysis, and problem-solving by students. In this pedagogical approach, one does not see RS materials as isolated technical tools, but rather as the means of cultivating more general cognitive, methodological, and digital skills that are the focus of 21st-century education. In spite of these identified possibilities, there is little active use of RS in school geography. The gap is caused by lack of didactically adjusted material, absence of methodological assistance to teachers, and the lack of coherent inclusion into curricula. As a result, although the number of applications in the RS technologies and their rapid evolution are evident, the transfer of the technologies into the constant and efficient teaching activities at the school level has not been developed yet.

This disparity between technological possibilities and educational practice is a serious research gap that needs to be conducted in a systematic way. Thus, the objective of the given study is to critically analyze the potential of RS materials in supporting the geographical literacy of students through a systematic literature review. By synthesizing and analyzing research results from international databases, the study aims to identify how RS has been integrated into geography classrooms, what challenges are currently observed, and what international experiences can serve as models to enhance classroom delivery in practice. In this way, the study provides both a theoretical background and a practical approach to the modernization of geography teaching and the improvement of geospatial literacy among secondary school students. To guide the analysis, the study addresses three research questions (RQ):

RQ1. How have RS materials been integrated into school geography in international practice?

RQ2.What pedagogical benefits and barriers of RS use in geography education are reported in the literature?

RQ3. How does RS contribute to the development of students' geospatial literacy and broader educational competences?

Based on prior research, the study advances the following hypothesis: while RS materials demonstrably enhance students' geospatial literacy, motivation, and competence-based learning, their broader integration into school geography is hindered by systemic challenges, particularly insufficient teacher training, infrastructural limitations, and the lack of curricular alignment.

The intended beneficiaries of this study are geography teachers and teacher trainers, who can directly apply RS in their instructional practice. At the same time, the review offers guidance for curriculum designers and policymakers in modernizing standards, as well as for researchers seeking to advance the academic debate on digital and geospatial competences in education.

Materials and methods

At present, one of the main problems limiting the active implementation of RS data in the educational process is the low availability of educational aerospace imagery that fulfils didactic requirements [6]. However, the experience of world scientists who have conducted research in this direction allows us to draw conclusions on the use of RS in teaching. Therefore, a systematic literature review (SLR) of research papers and articles was conducted to determine the relevance, theoretical basis, effectiveness, and opportunities for teaching using RS materials in the school geography curriculum.

The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to ensure transparency and replicability. The search was conducted in three major databases, Web of Science, Scopus, and PubMed, as they provide high-quality, peer-reviewed publications in both educational and environmental sciences. The search covered the period 2010–2024 to capture both foundational and the most up-to-date studies. The main keywords and Boolean combinations used were: "remote sensing" AND "school geography", "remote sensing" AND "geography education", "geospatial literacy" AND "teaching", "satellite imagery" AND "curriculum". Inclusion criteria were: (a) peer-reviewed journal articles; (b) studies explicitly focused on RS in the context of school geography education; (c) publications in English; (d) full-text availability. Exclusion criteria were: (a) duplicate records; (b) conference abstracts or short notes without full data; (c) studies unrelated to school-level geography; (d) inaccessible full-texts.

From an initial 43 records, 5 duplicates were removed, leaving 38 papers. After screening abstracts, 6 studies were excluded due to limited access to full-texts. 32 full-text articles were evaluated in detail. Of these, 7 studies were excluded at the eligibility stage because they either (i) focused exclusively on higher education, (ii) dealt only with technical aspects of RS without pedagogical application, or (iii) lacked empirical or didactic relevance. As a result, 25 articles were included in the final synthesis (Figure 1).

During the eligibility stage, the studies that explicitly addressed the pedagogical use of RS in geography classrooms were retained as high-relevance examples. For instance, Bodzin [13] and Bodzin & Cirucci [14] provided early models for integrating Google Earth and RS imagery into geography lessons. Cox et al. [15] and Zhu et al. [16] examined how RS can foster climate change education and interdisciplinary learning, while Adaktylou [17] demonstrated its value for phenomenon-based teaching in primary schools. Dziob et al. [18] and Núñez et al. [19] explored innovative practices such as flipped learning and interdisciplinary modules, and Osco et al. [20] reviewed the emerging role of UAVs and deep learning in RS education. These studies were coded as high-relevance because they directly connected RS with competence development, creativity, and environmental awareness in school geography.

The selected papers were then coded and thematically analyzed. An inductive coding procedure was applied: first, each study was read in detail and coded for its focus (e.g., creativity, motivation, teacher development, environmental awareness). Next, the codes were grouped into thematic categories reflecting the main pedagogical contributions and challenges of RS. This process ensured

that the analysis moved beyond descriptive statistics and provided a structured synthesis of benefits, barriers, and implications for practice.

To complement the qualitative synthesis, a bibliometric mapping was carried out using VOSviewer 1.6.17. The software was applied to visualize keyword co-occurrence networks and thematic clusters in the selected articles. This approach revealed dominant research trends such as the integration of RS into STEM curricula, its role in climate change education, and the importance of teacher training. The clustering of keywords also helped to identify gaps, such as the underrepresentation of professional development research and limited attention to curriculum reform. The visualization results thus contributed to both the classification of topics and the discussion of international experiences. In addition, the studies were classified by research methodology (qualitative, mixed methods, semantic analysis, scientometric analysis, etc.). This classification was important not only for descriptive purposes but also for assessing the strength of evidence across the literature. By mapping methodological diversity, it was possible to identify where empirical validation is stronger (e.g., mixed-methods designs) and where the literature relies more on conceptual or exploratory approaches. This step ensured that the review did not simply summarize studies but critically reflected on their methodological rigor.

We acknowledge several methodological limitations. First, the review was limited to three databases and to English-language studies, which may have introduced publication and language bias. Second, as a literature-based study, it does not provide empirical classroom validation, which should be addressed in future research. Third, the exclusion of certain non-indexed or regionally published works may have limited the scope of perspectives included. Finally, while PRISMA ensures transparency, the relatively small sample size (25 articles) constrains the generalizability of the findings. Nevertheless, by combining systematic screening, thematic coding, bibliometric visualization, and critical synthesis, the present study provides a replicable and methodologically rigorous account of how RS has been used in school geography, what benefits and barriers exist, and what implications can be drawn for curriculum development and teacher training.
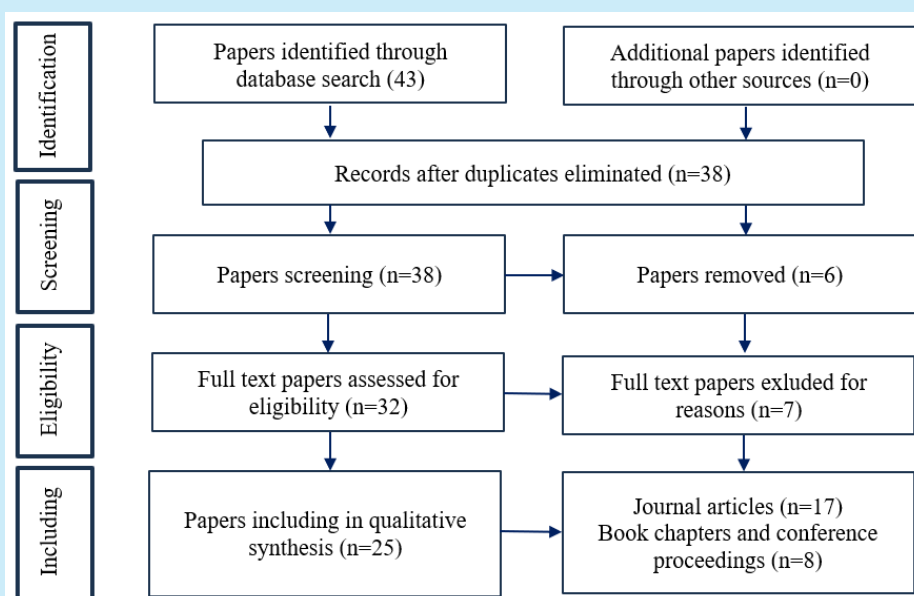

Figure 1. PRISMA flow diagram

Results

As a result of the study, through a systematic literature review of 25 papers that specifically explored the use of RS materials in the teaching of school geography, we found that 32% of the research papers were written in a creative and motivational way. In addition, 24% of the papers were aimed at explaining the benefits of RS materials in geography education (Table 1).

Table 1. Distribution of 25 papers by research area

№	Research Area	Number of Studies	Percentage
1	Benefits of RS materials in geography education	6	24.00
2	Learning and skills development	4	16.00
3	Creativity and motivation	8	32.00
4	Diversity and increased presence	3	12.00
5	Teacher professional development	5	20.00
Total		25	100

Furthermore, out of the 25 selected papers, 6 papers (24 %) used mixed research method, 4 papers (16 %) used qualitative data analysis method and the next 4 papers (16 %) used semantic network analysis method (Table 2). However, the method of scientometric analysis was the least used method (4%).

Table 2. Distribution of 25 papers by methodology

№	Methodology	Number of Studies	Percentage
1	Qualitative data analysis	4	16.00
2	PRISMA method	3	12.00
3	Metasynthesis approach	3	12.00
4	Mixed methods	6	24.00
5	Integrative review	2	8.00
6	Scientometric analysis	1	4.00
7	Semantic network analysis	4	16.00
8	Critical review	3	12.00
Total		25	100

In the course of the study, by analysing the works of scientists, the specifics and focus of each paper were determined and topics were proposed (Table 3). Of the 25 papers selected for the study, the highest number of papers were published in 2020-20%, 2021-16%, and 2019-12%.

Table 3. Distribution of 25 papers by theme

№	Authors	Dates	Themes
1	Simerská [3]	2023	The importance of RS in geography education
2	Prakash et al. [4]	2021	Implementation of RS in Geography Teaching: Potentials and Challenges
3	Nandi [8]	2016	Learning Methods of RS In the 2013 Curriculum of Secondary School
4	Voss et al. [9]	2008	Learning modules–A way to integrate RS methods in school education
5	Wu et al. [10]	2014	Application of RS in Training Geospatial Cognitive Abilities of Secondary Students
6	Bodzin [13]	2011	The implementation of a geospatial information technology (GIT)-supported land use change curriculum with urban middle school learners to promote spatial thinking
7	Dziob et al. [18]	2020	Interdisciplinary teaching using satellite images as a way to introduce RS in secondary school
8	Núñez et al. [19]	2020	Effectiveness of innovate educational practices with flipped learning and RS in earth and environmental sciences—An exploratory case study
9	Bednarz et al. [21]	2000	Mission geography: linking national geography standards, innovative technologies and NASA
10	Naumann et al. [22]	2009	RS in school–Theoretical concept and practical implementation
11	Saputro et al. [23]	2020	The Students Spatial Critical Thinking Skill by Using Map and RS Imagery on Geography Lesson
12	Lindner et al. [24]	2019	Expanding STEM Education in Secondary Schools: An Innovative Geography-Physics Course Focusing on RS
13	Ridha et al. [25]	2021	The problems of teaching geospatial technology in developing countries: Concepts, curriculum, and implementation in Indonesia.
14	Hilton [26]	2023	Geography and environmental science
15	Hodam et al. [27]	2020	Bringing earth observation to schools with digital integrated learning environments
16	Dannwolf et al. [28]	2020	Bringing earth observation to classrooms—the importance of out-of-school learning places and e-learning
17	Firomumwe [29]	2022	Exploring the opportunities of virtual fieldwork in teaching geography during covid-19 pandemic
18	Danaher et al. [30]	2021	Sustainability: A regional Australian experience of educating secondary geography teachers
19	Nellis [31]	1994	Technology in geographic education: Reflections and future directions
20	Kholoshyn et al. [32]	2021	The application of geographic information systems in schools around the world: a retrospective analysis.
21	Shakhislam et al. [33]	2024	Opportunities and challenges of using geospatial technologies in teaching school geography in Kazakhstan

22	Schulman et al. [34]	2021	Training teachers to use RS: The YCHANGE project
23	McCormack [35]	2010	Remotely sensing affective afterlives: The spectral geographies of material remains.
24	Agbaje et al. [36]	2019	Education and Training in Applied RS in Africa: The ARCSSTE-E Experience
25	Sanjoto et al. [37]	2019	Improvement of Geography Teacher's Skill in Making Learning Media Based on RS Image.

As shown in Table 3, 16% of the authors have published their articles in RS. More specifically: Dziob et al. [18], Hodam et al. [27], Dannwolf et al. [28] and Lindner et al. [38] published their research papers in this journal. Remote Sensing, journal is an international peer-reviewed open access mdpi journal dedicated to the science and application of RS technologies. The remaining authors have published their research in various publications as shown in Table 4.

Table 4. Distribution of 25 papers by publishers

№	Publishers	Number of Studies	Percentage
1	IEEE 2000 International Geoscience and Remote Sensing Symposium. Taking the Pulse of the Planet: The Role of Remote Sensing in Managing the Environment	1	4.00
2	International Journal of Online Engineering	1	4.00
3	Geografie	1	4.00
4	Book: Disruptive Technology, Industry 4.0, Advances in	1	4.00
5	Remote Sensing	4	16.00
6	E-Learning Tools, Techniques and Applications, Potsdam	1	4.00
7	In IOP Conference Series. Earth and Environmental Science. IOP Publishing.	1	4.00
8	Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.	1	4.00
9	In International Conference on Science and Education and Technology	1	4.00
10	In Geoinformatics Forum	1	4.00
11	Journal of Geography	1	4.00
12	In Satellite Technology in Education. Routledge.	1	4.00
13	Journal of Research in Science Teaching	1	4.00
14	International Journal of Geography and Geography Education	1	4.00
15	Education Sciences	1	4.00
16	Journal of Geography	1	4.00
17	In Journal of physics: Conference series. IOP Publishing.	1	4.00

18	International Research in Geographical and Environmental Education	1	4.00
19	Review of International Geographical Education Online,	1	4.00
20	Annals of the Association of American Geographers	1	4.00
21	International Journal of Geo-Information	1	4.00
22	In International Conference on Rural Studies in Asia. Atlantis Press.	1	4.00
Total		25	100

Thus, the literature review of the selected research papers identified the main research areas by using the keyword 'Teaching remote sensing in school geography'. As a result, it became clear that research in remote sensing, environmental monitoring, remote sensing technologies and ecosystems dominated (Figure 2).
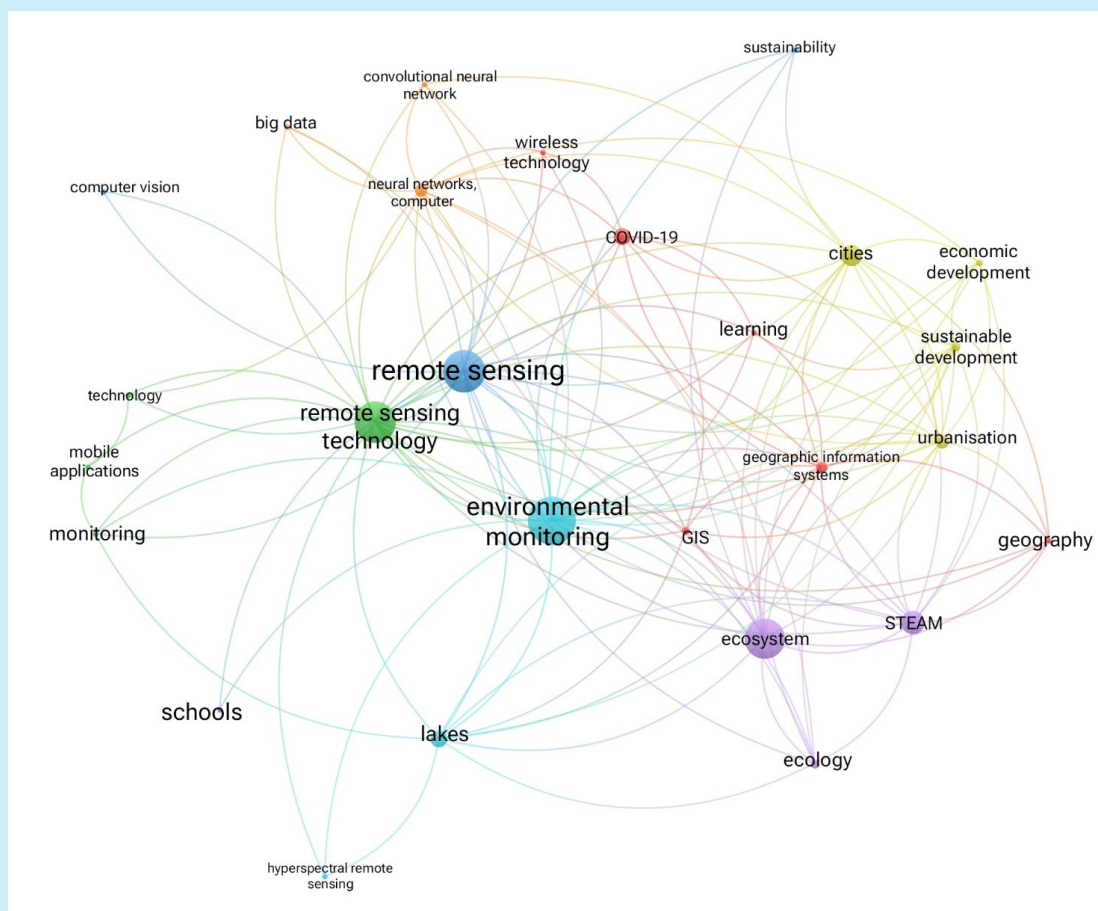

Figure 2. Keywords Teaching RS in school geography

These findings provide the basis for further discussion of how RS has been integrated in European school curricula.

Discussion

This study shows that there is still a partial utilization of RS materials in the geography of schools. Despite the fact that the systematic review indicated that an increasing number of studies focus on creativity, motivation, and the positive effects of RS applications, the evidence indicates that the actual practice in the classroom is haphazard and uneven. Professional development of teachers, alignment of the curriculum and development of didactically adapted materials are not sufficiently represented yet, even though the role of RS in enhancing geographical literacy is recognized. These findings are strengthened by international experiences. Under the example of Germany, RS is lacking in the standard secondary education when contrasted with the explicit presence of the subject in the contemporary educational systems that focus on information technologies [38]. These observations directly respond to RQ1 by showing how RS has been integrated into school geography across different contexts. The reviewed literature reveals that RS integration has taken the form of new interdisciplinary subjects (e.g., Geography-Physics in Germany), the use of digital and AR-supported tools in STEM lessons, and pilot projects aimed at embedding RS within environmental and sustainability education. However, these integrations remain uneven, fragmented, and often dependent on local initiatives rather than systemic adoption. The example of the pilot subject Geography-Physics, created with the involvement of the Universities of Bonn and Bochum together with the local secondary schools, demonstrates a new approach to integrating RS into the STEM education [24]. Under this initiative, hyperspectral data and augmented reality (AR) apps were brought to the classrooms. Nevertheless, even with these developments, there have been technological and pedagogical challenges to implementation, including lack of IT infrastructure and lack of familiarity with RS amongst new teachers

[39]. Such issues are direct reflections of the more general gap that we have found in our review, i.e. that interest in the RS integration is frequently greater than the institutional and infrastructural resources provided to facilitate its practical implementation. The same case occurs with the United Kingdom. A recent study by Hilton [26] that of all geography teachers, a third had not gotten any special training in RS and its applications to the environment, despite the growing availability of digital resources. This occurrence of teacher preparation is associated with the fact that comparatively few studies covered the professional development. It also reveals the fact that there is still a huge disjuncture between the potential of RS and the willingness of teachers to employ it properly in their classrooms. RS technologies may be used as potent climate education generators in Greece, the country that is highly susceptible to climate change. Nevertheless, Asimakopoulou et al. [40] have noted that education about climate change in schools has been sparse, in part because of the interdisciplinary nature of the topic and the institutional obstacles inherent in the day-to-day school-based practice. This is in line with our review that revealed that even though RS is commonly being introduced as a tool to promote environmental awareness, the same has not been a consistent part of the curriculum and its implementation requires numerous curriculum reforms. These cross-national findings provide an answer to RQ2, illustrating both the pedagogical benefits and the barriers of RS in geography education. On the one hand, RS promotes motivation, creativity, environmental awareness, and interdisciplinary competences. On the other hand, its adoption is limited by insufficient teacher training, infrastructural deficits, inflexible curricula, and the lack of didactically adapted resources. The literature therefore highlights a dual reality: RS is widely recognized as beneficial, yet systemic barriers prevent its consistent implementation in schools.

The Spanish example also indicates the educative value of RS. MartínezVega et al. [41] applied satellite imagery to map land use in Madrid to create thematic resource, which can easily be applied in classes. These exam-

ples demonstrate that the value of RS lies not only in general claims about improving geospatial thinking but also in its concrete pedagogical applications. In Spain, satellite imagery was used to interpret land-use changes and foster environmental awareness, while in Germany, AR-supported hyperspectral data facilitated STEM-based competences. Such cases illustrate how RS can lead to measurable learning outcomes when embedded into structured teaching strategies rather than being treated as supplementary material. Such resources not only reveal urban processes, but also help to develop the skills of environmental awareness and space reasoning of the students. This evidence addresses RQ3 by confirming that RS contributes directly to the development of geospatial literacy and broader competences. The reviewed studies demonstrate that RS enhances students' ability to interpret spatial data, fosters scientific inquiry and critical thinking, and supports competence-based and interdisciplinary learning. In this way, RS proves to be a pedagogical instrument that goes beyond visualization to actively build key 21st-century skills. These applications can be associated with the high level of creativity and motivation that we reviewed but also refer to the insufficient systemic structures to guarantee uniform application of RS in schools. Switzerland depicts opportunities as well as challenges. Although RS and digital approaches are scarcely represented in secondary education, the creation of special courses in RS and the establishment of the Web Hub gives encouraging perspectives of integration. Web Hub provides useful teaching modules and student project portals and teacher training. Surveys however show that the coverage of these initiatives is modest because of small sample sizes and self-assessment constraints. This once again points out that although we do have innovation; scaling and mainstreaming RS in education are still acute issues. Another applicable view is presented by Portugal. Indeed, the absence of GIS training and the inflexibility of curriculum schedules are barriers to the adoption of geospatial technologies as demonstrated by Esteves and Rocha [42]. This aligns with our discovery that there has been a minority of studies that have directly dealt with the

professional development of the teachers, a structural deficiency in the research on RS education at the present. In the absence of specific assistance, teachers cannot take advantage of the potential RS has to practice in the classroom. Along with these domestic experiences, the pioneer digital solutions like Geospektiv and Edu sat are the future-oriented solutions [43]. Geospektiv encourages the incorporation of Earth Observation data into geography curriculum and Edusat offers interdisciplinary, hands-on tools to help students be engaged with environmental concerns. Both sites display the potential of RS to be used as a connector between the scientific and practice-based in the classroom, giving youngsters concrete chances to acquire geospatial competences and environmental literacy. But their wider use is still in its infancy, and it needs planned assessment and institutional acceptance. Altogether, the evidence supports the main assumption of this paper: RS materials can play an important role in geographical literacy of students and in the modernization of teaching geography. However, as our findings, and our experience in other countries indicate, they have to be limited by structural factors, under-training of teachers, and the lack of curricular integration. To meet these challenges, there should be concerted efforts such as curriculum reform, investing in digital infrastructure, as well as designing professional development programs to be adopted by teachers. It is only in this way that RS technologies can cease being innovative add-ons and become integral to the teaching and learning of geography so that students can be better equipped to handle the demands of the growing interconnected and environmentally complex world

Although most of the reviewed studies originate from Western Europe, the implications extend to a wider range of educational contexts. The challenges identified, such as limited teacher training, infrastructural barriers, and insufficient curricular integration, are particularly relevant for developing countries, where resource constraints may further hinder the adoption of RS. At the same time, these regions present opportunities to leapfrog traditional approaches and embed RS technologies directly into modernized

curricula. Thus, while this review highlights European experiences, its findings provide transferable insights for both local and global contexts, underscoring the need for cross-regional comparative research. Taken together, the findings support the working hypothesis of this study: while RS materials demonstrably enhance geospatial literacy, motivation, and competence-based learning, their wider adoption is constrained by systemic challenges. The lack of teacher training, infrastructural limitations, and insufficient curricular integration repeatedly emerged across the literature, confirming that without structural reforms and policy support, RS will remain underutilized despite its strong pedagogical potential.

Conclusion

The primary objective of this study was to critically analyze the potential of remote sensing (RS) materials for supporting geographical literacy in school geography through a systematic literature review. Guided by the research questions – (RQ1) how RS has been applied in geography classrooms, (RQ2) what benefits and challenges have been identified in the literature, and (RQ3) what gaps and opportunities exist for future integration – the review synthesized evidence from 25 peer-reviewed articles. The findings show that while RS has been recognized internationally as a valuable tool for developing geospatial reasoning, motivation, and inquiry-based learning, its actual classroom implementation remains fragmented, constrained by limited teacher training, inadequate infrastructure, and the absence of consistent curricular integration.

This paper establishes that application of schools geography through the use of RS material can greatly improve students through geospatial literacy, spatial reasoning, and interdisciplinary competences. RS allows bringing the realistic data of the Earth observation into the classroom that, in addition to the motivation and interest in geo-environmental challenges, trains important scientific skills, including inquiry, interpretation of data, and systemic thinking. These conclusions substantiate the theoretical applicability of geospatial literacy theories and competency-based curriculum models, arguing that RS is not a technological device but a pedagogical one that does not only update the geography education system but also makes it work according to the requirements of learning in the 21st century.

The implications in practice are as well significant. To make RS a sustainable part of the geography education, teacher training, curriculum integration, and investment in infrastructures are needed. RS resources should be didactically modified to the classroom requirements, with the help of free-of-charge platforms as well as explicit methodological recommendations. To make sure that RS becomes a part of the national standards and to offer schools the digital resources to be used in the practice, policymakers and educators should cooperate. In the absence of these systemic changes, RS will not be fully used even though its potential has been proven.

There are a number of weaknesses that should be noted. There is also a limited literature base with most of the studies being conducted in Western Europe and no evidence of underrepresented areas. Another important limitation of this review is its reliance on secondary sources. While it synthesizes valuable international experiences, it does not include direct empirical validation such as classroom trials, teacher interviews, or student feedback. As a result, the findings remain largely conceptual and require further testing in practice to assess their impact on actual teaching and learning outcomes. There is a lack of methodological variety with a comparatively small number of longitudinal or experimental designs used to determine long-term learning outcomes. Moreover, the role of teacher professional development and institutional obstacles was also not well reviewed in the existing literature, which cannot be considered enough to assess the scalability of RS implementation in schools comprehensively. This does not mean that future studies should not continue to rely on the descriptive case study design, but rather the effectiveness of RS-based teaching in various educational

and cultural settings should be tested. This study is limited by its theoretical character, as it is based solely on the synthesis of existing literature and does not include a pedagogical experiment or empirical classroom validation. As a result, the integration of RS materials into recognized instructional design models (e.g., Bloom's taxonomy, constructivist approaches, inquiry-based learning) was not directly tested. Future research should therefore conduct classroom-based interventions to evaluate how RS contributes to different levels of learning outcomes, student motivation, and problem-solving competences. Such studies would allow for a stronger alignment between the technological potential of RS and established didactic frameworks, and provide teachers and policymakers with practical strategies for implementation.

Longitudinal research is required to identify the long-term effect of RS on the competences of students, whereas cross-national analysis would help to define what is best in terms of curriculum development and teacher training. Besides, the additional investigation of the policy and infrastructural circumstances under which RS can be implemented will be crucial to narrow the gap between the technology opportunities and practice in the classroom. Finally, RS technologies can turn the school geography into a subject that focuses on inert materials into a living subject using the real-life data and global issues. To do so, there is a need to take action both academically and in practice: conceptually, RS needs to be integrated into the educational systems, practically, it should be backed up with teacher education, restructuring of the curriculum and investment in online infrastructure. Only in this way can RS become a part of geography education, training students to critically address the challenges of the quickly evolving world.

The added value of this study lies in its systematic synthesis of international research on RS in school geography, going beyond isolated case descriptions to identify common patterns, recurring challenges, and transferable solutions. By explicitly linking RS to geospatial literacy frameworks and

competence-based education models, the review advances both theory and practice. It provides a foundation for curriculum developers, teacher trainers, and policymakers to systematically embed RS into geography education and thus contributes original insights to the ongoing modernization of the field. This study also has significant implications on pedagogy and curriculum development besides explaining the relevance of RS in enhancing geospatial literacy. The review demonstrates that RS materials have the capacity to motivate students, improve inquiry based learning and offer real, data rich contexts in the teaching of geography. Simultaneously, the results imply that the effective implementation should be associated with adherence to known instructional models including the taxonomy proposed by Bloom, constructivist pedagogical techniques, and inquiry. With the integration of RS into these models, teachers have an opportunity to go beyond the supplementary use to organized integration that builds a higher level of thought process skills, problem solving skills and environmental awareness. The current study, however, has weaknesses of being purely theoretical since it relies only on the synthesis of secondary sources without classroom testing. There was no direct testing of RS integration into instructional models and specific learning outcomes, student engagement and teacher feedback were not evaluated in the study. Future studies must hence use empirical research procedures such as pedagogical experiments, lesson design and measurement of the outcomes of learning to ascertain the applicability of RS in various school settings and grade levels. There is also a need to carry out comparative studies across geographical regions particularly in Kazakhstan and other related educational systems to localize global experiences. The creation of assessment instruments and quantifiable outcomes (e.g., better map-reading skills, spatial reasoning, or problem-based learning results) would increase the practical usefulness of RS in the teaching of geography further. The implications of this review are relevant for multiple audiences. For educators, RS should be introduced through practical teaching modules, open-access platforms, and targeted professional development that equips teachers

with both technical and didactic skills. For researchers, future studies need to move beyond descriptive reviews and undertake classroom-based experiments, longitudinal designs, and cross-national comparisons to measure how RS affects specific learning outcomes such as spatial reasoning, map interpretation, and problem-solving competences. For policymakers and curriculum developers, the findings underline the urgency of investing in digital infrastructure, embedding RS into national standards, and developing policy instruments that support schools in adopting innovative geospatial technologies. Only through coordinated efforts across these levels can RS evolve from a promising innovation into a sustainable pillar of geography education that equips students to critically address the challenges of an increasingly complex and interconnected world.

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Мектеп географиясын оқытуда қашықтықтан зондтау материалдарын әлеуетті пайдалану туралы әдебиеттерге жүйелі шолу

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Аңдатпа. Мектептегі географияны оқытуда жерді қашықтықтан зондтау (ЖҚЗ) материалдары жер жүйесінің негізгі компоненттерін біріктіруде ғылыми білімнің маңызды элементі ретінде өте маңызды рөл атқарады. Алайда мектеп географиясын оқытуда ЖҚЗ материалдарын қолдануға деген сұранысқа қарамастан, оларды қолдану төмен деңгейде қалып табылады. Сондықтан, бұл зерттеудің мақсаты мектеп географиясын оқытуда ЖҚЗ деректерін пайдалану мүмкіндіктері туралы әдебиеттерге жүйелі шолу жасау болып табылады. Бұл зерттеуде, біз PRISMA әдісін қолдана отырып, Web of Science, Scopus және PubMed дерекқорларында индекстелген ғылыми журналдарда жарияланған мақалаларды талдадық. Нәтижелер көрсеткендей, таңдалған 25 мақаланың 32% - ы шығармашылық және мотивациялық сипатта болса, 24% - ы қашықтықтан зондтау материалдарының географиялық білім берудегі артықшылықтарын түсіндіруге бағытталған. Сонымен қатар біріктірілген зерттеу әдісі бойынша 6 мақала (24%), деректерді талдаудың сапалы әдістерін қолдана отырып 4 мақала (16%), семантикалық желілік талдауды қолдана отырып 4 мақала (16%) жазылғаны анықталды. Саны бойынша 2020 жыл (20%) ең көп мақалалар жарияланған жыл ретінде анықталды. Авторлардың 16% - ы өз зерттеулерін Remote Sensing журналында жариялаған. Осылайша, біз Германия, Ұлыбритания, Греция, Испания және Португалия сияқты Батыс Еуропа елдерінің мектептерде географияны оқытуда ЖҚЗ материалдарын пайдаланудағы оң тәжірибесін анықтадық. Бұл зерттеу мектеп оқушыларының геокеңістіктік танымдық қабілеттерін ЖҚЗ материалдарын қолданудың тиімділігін негіздеу арқылы әдебиетке үлес қосуға бағытталған.

Систематический обзор литературы о потенциальном использовании материалов дистанционного зондирования в преподавании школьной географии

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Аннотация. В школьном обучении географии материалы дистанционного зондирования Земли (ДЗЗ) играют очень важную роль как важный элемент научного знания в интеграции основных компонентов системы Земли. Однако, несмотря на спрос на использование материалов ДЗЗ в преподавании школьной географии, их использование остается на низком уровне. Поэтому целью данного исследования является систематический обзор литературы о возможностях использования данных ДЗЗ в преподавании школьной географии. В этом исследовании мы проанализировали статьи, опубликованные в научных журналах, индексируемых в базах данных Web of Science, Scopus и PubMed, с использованием метода PRISMA. Результаты показали, что из 25 отобранных статей 32% были творческими и мотивирующими, в то время как 24% были сосредоточены на объяснении преимуществ материалов дистанционного зондирования в обучении географии. Кроме того, установлено, что по методу интегрированного исследования написано 6 статей (24%), 4 статьи с использованием качественных методов анализа данных (16%), 4 статьи с использованием семантического сетевого анализа (16%). По количеству 2020 год (20%) был определен как год публикации наибольшего количества статей. 16% авторов опубликовали свои исследования в журнале Remote Sensing. Таким образом, мы выявили положительный опыт западноевропейских стран, таких как Германия, Великобритания, Греция, Испания и Португалия, в использовании материалов ДЗЗ при обучении географии в школах. Данное исследование направлено на внесение вклада в литературу путем обоснования эффективности использования материалов ДЗЗ геопространственных познавательных способностей школьников.