EXPLORING THE RELATIONSHIP BETWEEN REMOTE SENSING RESEARCH AND THE SUSTAINABLE DEVELOPMENT GOALS

UZAKTAN ALGILAMA ARAŞTIRMALARI İLE SÜRDÜRÜLEBİLİR KALKINMA AMAÇLARI ARASINDAKİ İLİŞKİNİN İNCELENMESİ

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To my beloved wife and son

ABSTRACT

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The Sustainable Development Goals (SDGs), adopted by the 193 member states of the United Nations in September 2015, aim to address the challenges and barriers to sustainable development for the betterment of humanity and the planet Earth by 2030, and involve 169 targets and 231 one-of-a-kind indicators related to human and physical geography. The field of remote sensing (RS) / Earth observation (EO) has great potential to contribute to the realization of the SDGs by monitoring the indicators and evaluating the targets and tracking the policies in this area. Despite its limitations, the RS technologies present a synoptic view, repeatable and multiscale observations, and time-series data for monitoring the SDG indicators directly or indirectly. This study aims to explore the use of RS technologies in advancing the SDGs and analyze the existing literature using bibliometric techniques to identify research trends, gaps, and key contributors in the field of RS/EO in relation to the SDGs. In this study, the Web of Science (WoS) Core Collection database was used to explore SDG-related RS studies in a broad perspective, from bibliometric investigations to gender distribution in this domain. Subsequently, using the publications indexed in the same database, the relationship between RS/EO research and SDG 11 (Sustainable Cities and Communities) has been analyzed in detail with a more comprehensive methodology. This thesis has revealed the increasing trends in research on these topics, the most significant publications and journals in the field, the top-contributing countries, and international scientific collaborations. According to the results, carbon storage (linked to SDG 12), ecological quality (linked to SDGs 15, 14), and impervious surface (linked to SDG 11) have been found to be trending topics in remote sensing studies related to SDGs. In terms of gender analysis, it was observed that researchers are predominantly male. Through conceptual analyses, it was revealed that machine learning, a subset of artificial intelligence, serves as both a driving theme and a fundamental research area in this field. The results of the analysis are discussed extensively in the thesis and are expected to shed light for scientists working in these domains and policy makers, as well as for researchers who plan to work in this research area. Also, the results are expected to contribute to the existing body of knowledge and foster interdisciplinary collaboration in pursuit of the SDGs.

Keywords: Remote Sensing, Earth Observation, Sustainable Development Goals, Sustainable Development Goal 11, Science Mapping

ÖZET

UZAKTAN ALGILAMA ARAŞTIRMALARI İLE SÜRDÜRÜLEBİLİR KALKINMA AMAÇLARI ARASINDAKİ İLİŞKİNİN İNCELENMESİ

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Eylül 2015'te Birleşmiş Milletler'e üye 193 ülke tarafından kabul edilen Sürdürülebilir Kalkınma Amaçları (SKA), 2030 yılına kadar insanlığın ve Dünya gezegeninin iyiliği için sürdürülebilir kalkınmanın önündeki zorlukları ve engelleri ele almayı amaçlamakta ve beşeri ve fiziki coğrafya ile ilgili 169 hedef ve 231 benzersiz gösterge içermektedir. Uzaktan algılama (UA) / yeryüzü gözlemi (YG) alanı, göstergeleri izleyerek ve hedefleri değerlendirerek SKA'ların gerçekleştirilmesine ve bu alandaki politikaları izlemeye büyük katkı sağlama potansiyeline sahiptir. Sahip olduğu pek çok sınırlamaya rağmen, UA teknolojileri, SKA göstergelerini doğrudan veya dolaylı olarak izlemek için tekrar edilebilir ve çok ölçekli gözlemler ve zaman serisi verileri sunar ve sinoptik bir görüş sağlayabilir. Bu çalışma, SKA'ların ilerletilmesinde RS teknolojilerinin kullanımını keşfetmeyi ve SKA'larla ilişkili olarak RS / EO alanındaki araştırma eğilimlerini, boşlukları ve kilit katkıda bulunanları belirlemek için bibliyometrik teknikler kullanarak mevcut literatürü analiz etmeyi amaçlamaktadır. Bu çalışmada, Web of Science (WoS) Core Collection veri tabanı, SKA'lar ile ilgili uzaktan algılama çalışmalarını bibliyometrik analizlerden bu alandaki cinsiyet dağılımına kadar geniş bir perspektifte incelemek için kullanılmıştır. Ayrıca, yine aynı veritabanında indekslenen yayınlar kullanılarak, UA / YG araştırmalarının SKA 11 (Sürdürülebilir Şehirler ve Topluluklar) ile ilişkisi daha kapsamlı bir metodoloji ile detaylı olarak analiz edilmiştir. Bu tez, bu konulardaki araştırmaların artış eğilimlerini, alanın en önemli yayınlarını ve dergilerini, en yüksek katkı veren ülkeleri ve uluslararası bilimsel iş birliklerini ortaya koymuştur. Sonuçlara göre, karbon depolama (SKA 12 ile bağlantılı), ekolojik kalite (SKA 15 ve SKA 14 ile bağlantılı) ve geçirimsiz yüzey (SKA 11 ile bağlantılı) SKA'larla ilgili uzaktan algılama çalışmalarında popüler olmakta olan konular olarak bulunmuştur. Yayınlardaki cinsiyet dağılımına bakıldığında, araştırmacıların daha yüksek oranda erkeklerden oluştuğu saptanmıştır. Yapılan kavramsal analizler sonucunda, yapay zekânın bir alt kümesi olan makine öğrenmesinin bu alanda hem itici (motor) bir tema hem de temel teşkil eden bir araştırma alanı olduğunu ortaya çıkarmıştır. Analiz sonuçları tez içerisinde detaylı bir şekilde tartışılmış olup, politika yapıcıların ve bu alanlarda çalışan araştırmacıların yanı sıra bu alanlarda çalışmayı düşünen araştırmacılara da ışık tutması beklenmektedir. Ayrıca, sonuçların mevcut bilgi birikimine katkıda bulunması ve SKA'lar yolunda disiplinler arası işbirliğini teşvik etmesi beklenmektedir.

Anahtar Kelimeler: Uzaktan Algılama, Yer Gözlemi, Sürdürülebilir Kalkınma Amaçları, 11. Sürdürülebilir Kalkınma Amacı, Bilim Haritalama

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ABBREVIATONS

Abbreviations

AAGR	Average Annual Growth Rate
AI	Artificial Intelligence
BV	Beginning Value
CAGR	Compound Annual Growth Rate
CNN	Convolutional Neural Network
CNSA	China National Space Administration
EduSat	Educational Satellite
EO	Earth Observation
EO4SDG	Earth Observations for the Sustainable Development Goals
ESA	European Space Agency
EV	Ending Value
EVs	Essential Variables
GC	Global Citation
GCOS	Global Climate Observing System
GEE	Google Earth Engine
GEO	Geostationary Orbit
GEO	Group on Earth Observations
GHSL	Global Human Settlement Layer
GIS	Geographic Information Systems
ISRO	Indian Space Research Organization

LC	Local Citation
LEO	Low Earth Orbit
MCPs	Multi Country Publications
MDGs	Millennium Development Goals
MEO	Medium Earth Orbit
ML	Machine Learning
MODIS	Moderate Resolution Imaging Spectroradiometer
MoI	Means of Implementation
NASA	National Aeronautics and Space Administration
OSDG	Open Source SDG
PY	Publication Year
RS	Remote Sensing
RSEI	Remote Sensing-based Ecological Index
SCPs	Single Country Publications
SDGs	Sustainable Development Goals
UN	United Nations
UNEP	United Nations Environment Programme
WoS	Web of Science

1. INTRODUCTION

This chapter aims to present the problem definition, key research questions, thesis objectives and thesis contribution, respectively, and the organization of the thesis is given at the end of it.

1.1. Problem Definition

Established by the United Nations in 2015, the Sustainable Development Goals (SDGs) are a worldwide call to action to eradicate poverty, protect the Earth, and ensuring that all people are able to enjoy peace and prosperity. These 17 interconnected goals address the most pressing global challenges we face, ranging from poverty and inequality to climate change and sustainable cities and communities. The 2030 Agenda recognizes the intertwined nature of the Sustainable Development Goals across sectors, but lacks explicit guidance on how to achieve this integration (Cernev & Fenner, 2020).

The SDGs have been presented as a global effort, supported by significant institutional tracking systems focused on ensuring the successful implementation of related policies (Weber, 2017). They aim to be transformative yet flexible enough for country-specific application and this briefing avoids a rigid definition of the core SDG principle of leaving no one behind (Stuart & Samman, 2017). The SDGs can be used to create a world focused on inclusive growth, translating the pledge to "leave no one behind" into concrete steps for improved development practices (Mills, 2015).

The role of Earth Observation (EO) and satellite data in the implementation of the SDGs has been increasingly recognized (Aleksieva-Petrova et al., 2022). Given their effectiveness and growing popularity, the Remote Sensing (RS) technologies have progressively been used to measure the SDG indicators (Chirici, 2020), such as those relevant to urban development in line with Goal 11 (Ghazaryan et al., 2021). Despite certain limitations, RS technologies provide a comprehensive perspective, consistent and multiscale observations, and temporal data that support the direct or indirect monitoring of SDG indicators.

This thesis is centered on the role of RS in achieving the SDGs, and investigated the current state and future of remote sensing in monitoring and assessing these goals globally by 2030. The constant flow of new information and technologies into the fields of RS and the SDGs, and the search for new solutions to meet current needs, brings with it a number of problems. The biggest of these problems is the difficulty for a researcher or policymaker to access the information they need from a huge corpus of knowledge, like looking for a needle in a haystack. The rapid accumulation of knowledge in the joint area where RS and SDGs intersect has made it very difficult to process and access the desired information using manual methods. Due to the nature of science, this cumulative increase in knowledge (Zeigler, 2012) has already gone beyond manual processing and necessitated the use of science mapping analysis software tools and artificial intelligence (AI). With science mapping, an image can give a snapshot of what is to be explained in paragraphs, allowing complex information sets to be visualized and thus easier to understand. It also saves time.

It should be emphasized that RS and the integration of artificial intelligence tools into RS domain, can be the key to continuous and effective monitoring of indicators related to the SDGs (Ekmen and Kocaman, 2024). Urban RS is essential for sustainable cities and communities (Ekmen and Kocaman, 2023), and is the solution to many problems, from urban planning to the terms that begin with the word "urban". All these problems and needs, such as bringing this extensive knowledge to the reader by concretizing it with quantitative measures, identifying areas that have not yet been sufficiently explored, and providing starting points for researchers who are eager to explore this field, have been important factors in the emergence of this thesis.

Therefore, this study aims to support progress in this cross-cutting area by shedding light on researchers who are and will be conducting RS studies that can contribute to the realization of the SDGs (especially SDG 11). It also aims to help policy makers identify current and future policy and funding priorities. All these needs and potentials are the motivation behind the development of this work.

1.2. Key Research Questions

Based on the problem definition introduced above, the main research questions of this thesis can be listed as follows:

- What is the evolution pattern of published research on remote sensing in relation to the SDGs, and the SDG 11 (Sustainable Cities and Communities) in particular?
- Could science mapping analysis tools be used to determine prevailing research trends and identify unexplored areas in the application of remote sensing for achieving and complying with the SDGs and in particular, SDG 11?
- Which countries have been the leading contributors to the RS research related to the SDGs, particularly SDG 11, and which of these have the most robust international collaborations?
- Can specific tools and procedures be suggested to facilitate the search and retrieval of information, the analysis of results, and the drawing of meaningful conclusions and interpretations for similar efforts?

1.3. Thesis Objectives

Based on the above-mentioned problem definition and the key research questions, the main objectives of this thesis were determined as:

- To explore the links and analyze the patterns between the SDGs, and in particular SDG 11, and the discipline of remote sensing in the scientific literature.
- To describe the evolution in the field and identify the gaps and challenges, in order to support policy makers in defining future directions.
- To conduct a detailed analysis of SDG 11, which addresses the need to make cities and communities sustainable, as it has a significant relationship with urban remote sensing and geomatics applications.

Based on the findings, useful recommendations and options for future research agendas were proposed. It is expected that future research could use this study as a starting point to find more connections or add quantitative analysis.

1.4. Thesis Contribution

The novelty of the study, as well as some of the scientific contributions that the thesis is expected to provide, can be summarized as follows:

1. Despite the fact that there are bibliometric studies on both RS and the SDGs, none existed on the intersection of both fields. Thus, this thesis has taken a systematic approach to fill this gap, developed a unique work with additional analyses (sorting literature by SDGs using an artificial intelligence-based tool and gender distribution), and analyzed the relationship between the RS and SDG 11. Therefore, this work is novel and contributed to the knowledge in the field.
2. The current state of the research area was presented in a deductive logic, moving from the general to the specific (first the relationship between the RS and the SDGs, and then the relationship between the RS and SDG 11). In this way, the role and importance of RS technologies in achieving the SDGs and in particular SDG 11 were emphasized.

3. Keyword analysis indicated the interdisciplinary nature of the research area and thus the need for a holistic approach.
4. Contributions to the cross- cutting area of RS and SDGs at the country level and reflection of international cooperation in science in the field were investigated and the outcomes showed that there is intense international scientific cooperation in this research area.
5. The importance of the use of the AI technologies in analyzing the state-of-the-art has been emphasized.
6. The snowballing nature of information makes it increasingly difficult to find the information that is sought. A contribution in line with this fact is that it may be possible to make it easier to find and access the desired information from the colossal information in the field. This convenience is especially important for new researchers who are eager to work in the field.

1.5. Organization of the Thesis

This thesis is presented in subsequent six chapters:

Chapter 1 (Introduction): The importance of the SDGs, the importance of RS in SDG monitoring, and the main research questions and contribution of the thesis were presented.

Chapter 2 (Background): Key concepts and terminology of the thesis were explained in this chapter. Also, some related studies are mentioned in order to establish the context and relevance of the thesis, review the existing research and identify the relevant gap in the literature.

Chapter 3 (Methodology): The data and the methodology used in the thesis were described here.

Chapter 4 (Results): This chapter explored the results of the study and included analysis and interpretation of the results.

Chapter 5 (Discussion): This chapter discussed the results of the analyses and the achievements and the limitations of the study.

Chapter 6 (Conclusions and Future Work): A summary of the analyses carried out in this thesis was given together with a roadmap for future work.

2. BACKGROUND

This chapter introduces the main concepts related to the thesis subject and describes the existing work that can serve as a basis for better understanding the thesis and determining the boundaries of the thesis.

2.1. A Definition of Remote Sensing

The RS encompasses a wide range of definitions and concepts. Fussell et al. (1986) categorized these definitions into three groups such as a science or art, as a tool or technique, or as a functional activity. Based on their literature review, Fussell et al. (1986) found that the RS experts overwhelmingly prefer functional and minimalist definitions. Shanmugapriya et al. (2019) described the RS as the discipline of obtaining information about objects or areas from a distance, without direct physical contact.

The RS is essentially both a scientific and a technological method for obtaining data about an object or phenomenon without making physical contact with it. This definition involves a distinction between science and technology. Based on this definition, it may be necessary to discuss the difference between science and technology. The debate on the epistemological relationship between science and technology is not new (Boon, 2011). The term technology is derived from the Greek word "techne" (craft), and according to Aristotle, unlike knowledge (episteme), craft is practical and mutable (Kline, 1985). Auguste Comte believed that science was the pinnacle of intellectual understanding (Schumaker, 2010). On the other hand, technology is the application of scientific knowledge to meet human needs and improve the quality of life. Nevertheless, it is difficult to characterize, technology refers to the application of science especially for the needs and comfort of people. According to Günay and Ariduru (1999), modern science integrates experimental methods with theoretical analysis, harmonizing empirical observation and rational thought to advance scientific knowledge. In contrast, technology applies this scientific knowledge to meet human needs and improve the quality of life.

Since the 1970s, the use of RS technology has increased significantly (Avtar et al., 2020). This technology provides practical and cost-effective data, especially for large, remote, mountainous, hazardous, and inaccessible areas. The RS and Earth observation (EO) technologies are versatile, enabling the monitoring of different issues and challenges at different scales, from local to global, and over different time frames. Despite their limitations, the amount of accessible remote sensing data has increased exponentially. Although the RS and EO are often used interchangeably, the EO has been preferred in satellite studies of the Earth, suggesting that the RS is a broader term that includes EO, as reflected in the interchangeable usage throughout this study.

Recent advances in the RS/EO involve the use of different sensors, including optical and radar types; satellites in different orbits, such as geostationary orbit (GEO), low Earth orbit (LEO), or medium Earth orbit (MEO) which is positioned between GEO and LEO in terms of altitude. In addition, there have been advances in data processing and analysis methods, such as the application of machine learning techniques, both supervised and unsupervised, depending on the data context, and data fusion methods. The increasing availability of RS/EO systems, as illustrated in Figure 2.1, together with the development of automated interpretation and analysis techniques, has gradually increased their potential to make substantial contributions to the achievement of the SDGs.

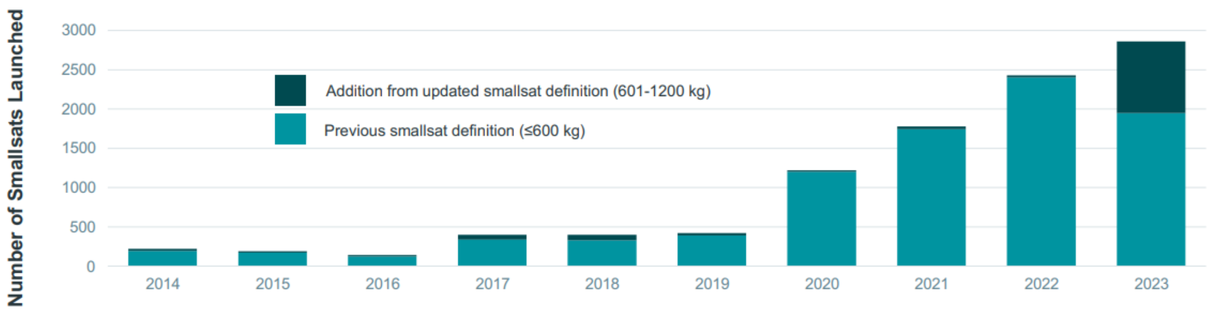

Figure 2.1. Small Satellites Launched According to Year (BryceTech, 2024).

Satellites are classified in various ways according to their mass. For example, small satellites (satellites under 500 kg) have been used for a variety of missions and the strongest motive for small satellites have been recently EO. (Kopacz et al., 2020). Moreover, launch costs of approximately $100 to $400 million for conventional large satellites are reduced to approximately $40,000 for small satellites thanks to their light weight and small size (Song et al., 2024).

The benefits of satellite technologies are numerous. For example, satellite technologies are also making a significant contribution to Global Climate Observing System (GCOS) and education. Satellite observations represent a critical component of GCOS for observing the climate system (Kocaman & Seiz, 2023). As for education, a great example of this was in 2004, when the Indian Space Research Organization (ISRO) launched EduSat (educational satellite), a satellite designed specifically for the education sector (Iyer, 2014). As the size and diversity of space programs supported by governments and the private sector have also increased, policies and regulations in this area have had to be further developed to ensure efficient use and to realize their full potential. One example is European Space Agency's (ESA) the Earthnet Programme (ESA, 2020). The agency is committed to strengthening its collaboration with commercial space mission providers and other global space agencies, a move that aims to increase the global adoption and use of Earth observation data, as described by Mannan et al. (2019). NASA also supports the widespread use of EO data through its Earthdata website, which provides free and open access to EO data (Earthdata, n.d.)

2.2. Sustainable Development and the United Nations' SDGs

Sustainability, a term rooted in the Latin "sustinere" (from "sus" meaning up and "tenere" meaning to hold), suggests a holistic approach that integrates environmental, social, and economic considerations to shape a future that improves the overall quality of life (Jeronen, 2013). The term sustainability evolved from "sustained yield," a concept that dates back to the mid-19th century as an almost direct translation from the German "nachhaltig" (Grober, 2007). The idea first appeared in print in 1713, more than two and a half centuries before the Brundtland Report, in "Sylvicultura oeconomica," the first extensive manual on forestry written by the German aristocrat Hanns Carl von Carlowitz (Grober, 2007). Sustainability is often described as the ultimate goal, while sustainable development is seen as the way to get there (Washington, 2015). Sustainability is a concept that sits on 3 pillars. These pillars are social, environmental and economic. The three-pillar conceptualization of sustainability is a mainstream approach in the literature (Purvis et al., 2019). However, it is difficult to say that all scholars agree on the number of these pillars. For example, cultural sustainability was presented as an additional pillar of sustainability by Hawkes (2001).

The term sustainable development became popular with the Brundtland Report entitled "Our Common Future" (Brundtland, 1987; Du Pisani, 2006), which addressed the environmental challenges of post-World War II reconstruction as part of the post-war international economic system and the social concerns of uneven development, poverty, and population growth. The concept of sustainable development was described in the report as satisfying the needs of the present without sacrificing the ability of later generations to satisfy their own needs (Brundtland, 1987). The Brundtland Report is widely credited with introducing a definition of sustainable development that links economics and ecology, but this definition has been both widely accepted and criticized (Telfer, 2012).

As part of institutional and global efforts, the United Nations (UN) commissioned the Millennium Development Goals (MDGs) in 2000 and set eight goals to reverse the devastating poverty, hunger, and disease affecting billions of human beings by 2015 (UN MDGs, n.d.). The MDGs follow a historical line of global commitments to alleviate human suffering, dating back to initiatives such as President Franklin D. Roosevelt's "Four Freedoms" speech in 1941 and the 1948 Declaration of Human Rights (Hulme, 2009). The MDGs were instrumental in raising global awareness, eliciting social responses, and generating significant public and political momentum (Sachs, 2012). A set of 21 targets and 60 indicators was used to monitor progress toward the MDGs (Simkiss, 2015). Although the MDGs have been the subject of criticism for their insufficient results (Pizzi et al., 2020), thanks to the progress secured by the MDGs, the UN decided to expand the scope of the MDGs by establishing a set of 17 goals, typically referred to as the Sustainable Development Goals or the Global Goals. In September 2015, these goals were formally adopted at the UN headquarters in New York (United Nations, 2015) by the 193 sovereign member states of the United Nations. Compared to the MDGs, the SDGs are broader in scope and focus (Table 2.1).

Table 2.1. MDGs vs. SDGs: Goals, targets, and indicators.

	MDGs	SDGs
Goals	8	17
Targets	21	169
Indicators	60	231
Focus	Developing Countries	All Countries

The official titles of the 17 SDGs, as seen on the SDG poster (Figure 2.2), are as follows:

- Global Goal 1: No Poverty
- Global Goal 2: Zero Hunger
- Global Goal 3: Good Health and Well-being
- Global Goal 4: Quality Education
- Global Goal 5: Gender Equality
- Global Goal 6: Clean Water and Sanitation
- Global Goal 7: Affordable and Clean Energy
- Global Goal 8: Decent Work and Economic Growth
- Global Goal 9: Industry, Innovation and Infrastructure
- Global Goal 10: Reduced Inequalities
- Global Goal 11: Sustainable Cities and Communities

- Global Goal 12: Responsible Consumption and Production
- Global Goal 13: Climate Action
- Global Goal 14: Life below Water
- Global Goal 15: Life on Land
- Global Goal 16: Peace, Justice and Strong Institutions
- Global Goal 17: Partnerships for the Goals

Figure 2.2. The SDG poster (United Nations, 2019).

The SDGs are intended to help the world set a vision for the next 15 years by 2030. The SDGs are underpinned by 169 targets. These targets are divided into outcome targets and means of implementation (MoI) targets. Although this distinction is a distinction between "ends" and "means," which together determine better or worse results (Weber & Weber, 2020). Therefore, the MoI targets hold equal importance to the outcome targets (United Nations, 2015). Each of the first 16 SDGs contains specific outcome targets with numerical labels (e.g., 15.1, 15.2) and a few letter-coded MoI targets (e.g., 15.a, 15.b), while Goal 17 is devoted solely to outlining the strategies for achieving all of the SDGs

(Bartram et al., 2018). The table below (Table 2.2) demonstrates the distribution of outcome targets and MoI targets by SDGs.

Table 2.2. Distribution of outcome and MoI targets across the SDGs.

SDG #	Number of Outcome Targets	Number of MoI Targets	Total Targets
SDG 1	5	2	7
SDG 2	5	3	8
SDG 3	9	4	13
SDG 4	7	3	10
SDG 5	6	3	9
SDG 6	6	2	8
SDG 7	3	2	5
SDG 8	10	2	12
SDG 9	5	3	8
SDG 10	7	3	10
SDG 11	7	3	10
SDG 12	8	3	11
SDG 13	3	2	5
SDG 14	7	3	10
SDG 15	9	3	12
SDG 16	10	2	12

The progress and the achievements of the targets are monitored through indicators. Indicators are used to monitor progress and achievement of goals. In fact, the total number of indicators is more than 231 if repetitions are taken into account.

2.3. SDG 11: Sustainable Cities and Communities

Cities go beyond being mere repositories of inhabitants, goods, and intellect, as Egger noted in 2006. They embody social manifestations that require elements of management, governance, economics, culture, education, and community engagement to create an environment conducive to human life and social interaction.

A sustainable city, also known as an eco-city, is designed with the three pillars of sustainability - social, economic, and environmental - in mind to create a resilient environment for today's population without compromising the ability of succeeding generations to do the same (Trinder & Liu, 2020). However, research by Hassan and Lee (2015) suggests that the term "sustainable city" may restrict the possibilities for advancing sustainability in future efforts. They suggest that the term "transition toward the sustainable city" may be a more accurate and effective description.

As urbanization accelerates worldwide, the most pressing sustainability challenges of the 21^{st} century are expected to emerge in urban areas (Katila et al., 2019). With two-thirds of the global population projected to live in urban areas by 2050, the importance of effective urban planning to promote sustainable community growth is becoming increasingly important (Russell, 2018). This focus is reflected in particular in Goal 11, which is dedicated to sustainable cities and communities. The official wording of SDG 11 is "make cities inclusive, safe, resilient and sustainable" (United Nations, 2015). This goal is of 10 targets. Of these 10 targets, 7 are outcome targets and 3 are MoI targets. In addition, Global Goal 11 has 15 indicators. These targets and indicators are tightly linked to potential urban transformations towards sustainability (Koch & Krellenberg, 2018).

The SDGs interact with each other and it is safe to say that SDG 11 can touch all SDGs in some way. For example, SDG 11 enhances SDG 15 by advocating for sustainable urbanization (Target 11.3), better urban planning (Targets 11.2, 11.b, 11.c), green infrastructure (Target 11.7), safe waste management (Target 11.6), and the protection of natural heritage (Target 11.4), while SDG 15 advances sustainable cities via nature-based solutions and disaster risk reduction (UN Habitat, 2018).

2.4. Bibliometrics and Science Mapping

The origins of bibliometrics can be dated back to the late 19th century, specifically the 1890s (Osareh, 1996). However, the term bibliometrics was first proposed by Alan Pritchard in his article entitled "Statistical Bibliography or Bibliometrics" in 1969 (Pritchard, 1969). Bibliometric studies provide various insights into scholarly communication by examining certain characteristics of publications (Al et al., 2010). The results of citation analysis can be used to assess the scientific research activities in the respective field of study (Umut & Coştur, 2007). Although citations are mainly used to document or strengthen the scientific basis, they can be used for different reasons (Garfield, 1965). Garfield (1965) highlighted, inter alia, including paying homage to pioneers, identifying the means such as methodology and equipment, providing background reading, and criticizing previous work and alerting the forthcoming ones, and identifying original publications based on ideas, concepts or terms.

Bibliometrics, as a quantitative science, can be divided into two sub-areas, counting productivity (descriptive) and counting literature use (evaluative) (Drake, 2003). Commonly used bibliometric analyses include bibliographic coupling, co-citation, co-word, and many other variations.

On the other hand, scientific mapping, which is an important research topic in the field of bibliometrics, is a visual representation of the structure and dynamics of a research field. For scientific writing, a spatial display can help understand how concepts relate and progress (Small, 1999).

2.5. Studies on Remote Sensing in the Context of the SDGs

The SDGs serve as an expanded framework compared to the previous Millennium Development Goals (MDGs), particularly in their efforts to link the social, economic, and environmental dimensions of the goals (Stafford-Smith et al., 2017). These SDGs provide an integrated and comprehensive framework of 17 goals, 169 targets, and 231 indicators to guide, monitor, implement, and assess the progress of nations toward sustainability by 2030 (Zhou et al., 2022).

The RS technologies have proven to be a valuable asset in tracking and assessing the targets and indicators of the SDGs. A study conducted by the Group on Earth Observations shows that Earth observations have the potential to have a direct or indirect impact on 72 targets and 30 indicators (EO4SDG, n.d.). This analysis highlights the particular relevance of EO data for Global Goals 6, 14, 15, and 11 (EO4SDG, n.d.), indicating that these goals are particularly amenable to support from remote sensing and EO techniques. Therefore, some remote sensing studies that are particularly relevant to these four Global Goals will be mentioned below.

SDG 6 focuses on ensuring that people have access to clean water and sanitation. The National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and the China National Space Administration (CNSA) have launched EO initiatives and developed methodologies that help track and assess SDG targets 6.1, 6.3, 6.4, 6.5, 6.6, and 6.a (Lu et al., 2021). Changes in the extent of water-based ecosystems over time are measured under SDG indicator 6.6.1 (UNSTATS, 2024). In the study by Hakimdavar et al. 2020, the authors detail a study aimed at demonstrating the capacity of EO data to support national reporting for SDG indicator 6.6.1. They explore the extent to which, and the conditions under which, current or future EO data products could be used for reporting on this indicator. This includes a thorough review of the data collection process, following the monitoring methodology established by the United Nations Environment Programme (UNEP). Miao et al. (2023) conducted a study in the National

Innovative Demonstration Zone for Sustainable Development in Lincang City. This study used a combination of different data sources, including remote sensing information, to investigate the progress and current situation of achieving SDG 6 from 2015 to 2020.

Global Goal 14 aims to protect and sustainably use the oceans, seas and marine resources for sustainable development. RS technologies have been used to monitor water quality in many places, including Belize (Osborn, 2022), Namibia (Kapalanga et al., 2021), and India (Kulk et al., 2021). In the study by Tan et al. (2022), Moderate Resolution Imaging Spectroradiometer (MODIS) imagery was used to study water clarity in Qinghai Lake from 2001 to 2020.

SDG 15 aims to conserve, restore and promote the sustainable use of land-based ecosystems, sustainably manage forests, combat desertification and stop land degradation and biodiversity loss. The increasing availability of medium to high resolution EO data (e.g., from Landsat or Sentinel satellites), combined with improved computing and storage capabilities, makes it possible to monitor, map, and assess land degradation and its progression over time on a national scale in a precise, consistent, and systematic manner (Giuliani et al., 2020). In this context, land cover maps often serve as essential datasets to isolate specific land cover categories prior to calculating SDG indicators, such as SDG 15.1.1 and SDG 15.3.1 (Maso et al., 2023). SDG 15.3.1 indicator measures the proportion of degraded land as a percentage of total land area (UNSTATS, 2024). In their research, Reith et al. (2021) used local datasets in conjunction with remotely sensed imagery to track land degradation in two semi-arid districts in Tanzania from 2000 to 2019.

Global Goal 11, whose relationship to RS is analyzed in detail in this thesis, aims to create cities and human communities that are inclusive, safe, resilient, and sustainable. RS techniques can capture urban growth and its changes (Xian & Crane, 2005). In the 2021 study, Zhang and colleagues aimed to refine the assessment of sustainable urban development by adapting SDG 11 indicators to local contexts and combining Earth observation with other data (e.g., statistical data) at the city and county levels. This example alone can demonstrate the importance of EO in building sustainable cities, and highlights the usefulness of satellite data in tracking developments in urban environments and green spaces.

To identify and map how best to operationalize the EO data to achieve the SDGs and be ready for a post-2030 agenda that develops new indicators and/or sub-indicators, it will be useful to take action in light of related work. In addition, indicators should be specific, measurable, achievable, relevant, and time-bound (SMART) to make the Global Goals achievable and direct (Essex et al., 2020). Indicators for a post-2030 agenda should also be SMART.

2.6. Bibliometric Analysis in the Fields of RS and the SDGs

Bibliometrics is becoming increasingly popular in many disciplines, and the field of RS is no exception. Performing the WoS query: (ALL=(remote sensing) AND ALL=(bibliometric*)), it was found that between 2007 and 2023 there were 285 publications that fell under the intersection of RS and bibliometrics (Figure 2.3). From only 1 publication in 2007, the number of publications started to increase steadily in 2019, reaching 94 publications in 2023. Similarly, the number of citations, which was 191 in 2019, peaked in 2023 and reached 1565 citations (Clarivate WoS, 2024).

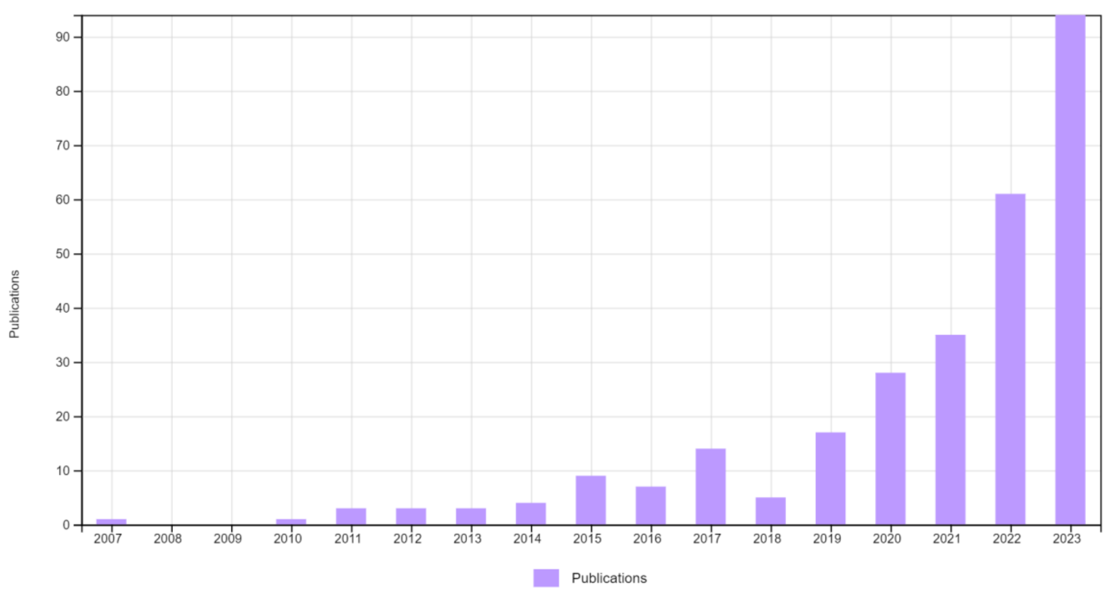

Figure 2.3. The number of documents obtained from the query: (ALL=(remote sensing) AND ALL=(bibliometric*)) AND (PY=(2007-2023)) (Source: Clarivate WoS, 2024).

By analyzing these 285 publications, it is possible to talk about a wide range of topics from drone use in agriculture (Rejeb et al., 2022) to the RS in archaeology (Agapiou & Lysandrou, 2015), RS applications in health (Viana et al., 2017) to oil spill mapping (Vasconcelos et al., 2020).

For example, the study by Santos et al. (2021) pointed out the main results of publications on "wildfires" and "remote sensing" in the period between 1991 and 2020. In this study, they used Scopus as a database and VOSviewer (Van Eck & Waltman, 2010) as a bibliometric analysis software tool. The 2022 study by Bai and collaborators focused on deep learning in RS. In the study, which emphasized that the convolutional neural network (CNN) is the most commonly employed deep learning method in the field, CiteSpace (Chen, 2004) was used as a bibliometric analysis software tool.

The increasing trend and popularity of bibliometric studies in the field of remote sensing can also be seen in the SDGs. Performing the WoS query: (ALL=(Sustainable Development Goal*) AND ALL=(bibliometric*)), it was found that between the year 2016, when the SDGs will come into effect, and the year 2023 there were 637 publications that fell under the intersection of the SDGs and bibliometrics (Figure 2.4). As can be seen from the graph (Figure 2.4), there was a significant increase in both the number of publications and citations from 2016 to 2023. Starting with only one publication and two citations in 2016, the number of publications and citations continuously increased from year to year, reaching a peak of 262 publications and 3908 citations in 2023 (Clarivate WoS, 2024). This increasing trend shows that the popularity of bibliometric studies on the SDGs is gradually growing in the academic community. It also indicates the attractiveness of the research field at the intersection of bibliometric studies and the SDGs. With the prediction that this trend will continue in the coming years, it can be concluded that more studies will be conducted in this research area.

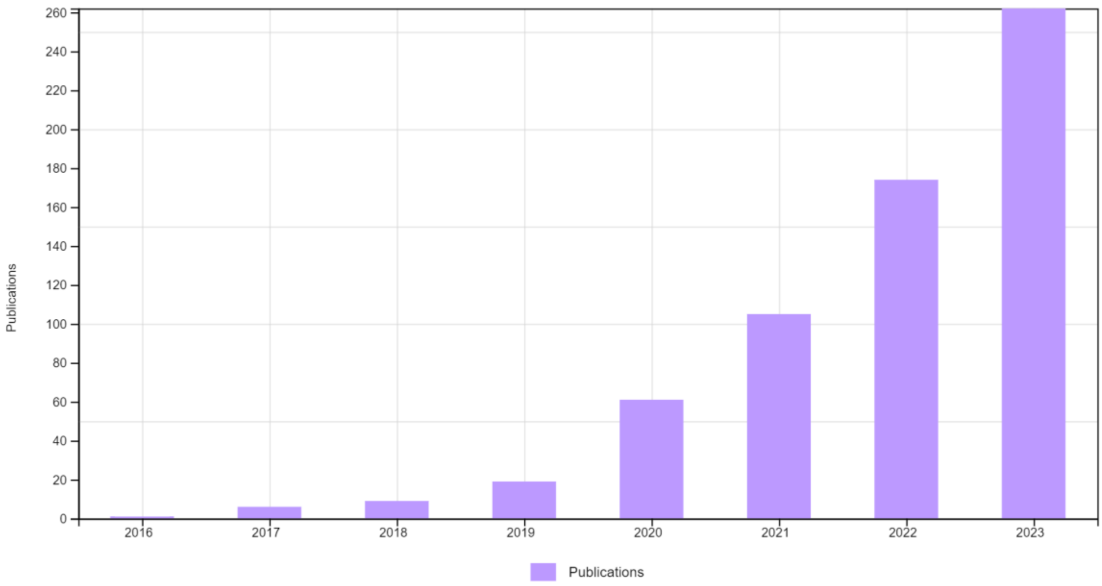

Figure 2.4. The number of documents obtained from the query: (ALL=(Sustainable Development Goal*) AND ALL=(bibliometric*)) AND (PY=(2016-2023)) (Source: Clarivate WoS, 2024).

Looking at the publications in the field, it is possible to see that bibliometric analysis has been used in a wide variety of subjects. Gajdzik et al. (2020) were conducted a bibliometric analysis on the theme "Sustainable Industry 4.0" and supported a thesis that validated the possibility of combining Industry 4.0 and SDGs with Sustainable Industry 4.0. Reis et al. (2021) proposed a framework for the development of Sustainability 4.0, which is a broader concept than Sustainable Industry 4.0. The study adopted bibliometric analysis methods along with content analysis. In a separate publication (Gao et al., 2021), the carrying capacity in the scope of SDGs was examined using a data set of 897 records. Obaideen et al. (2023), using the keyword "solar", found that more than 70% of solar research is related to SDG 7. For this study, they used the Scopus database. Dibbern et al. (2022) conducted a bibliometric study on Global Goal 6 using the WoS data. Another bibliometric study on SDG 6 was conducted by Basu and Dasgupta (2021), based on 637 articles. Beloskar et al. (2024) performed a bibliometric study on gender equality (SDG 5) and identified popular research themes in this domain. In an intriguing bibliometric study, Meitei et al. (2023) examined the use of AI and machine learning (ML) to the realization of SDGs. This study underlined the potential of AI in relation to the SDGs.

Bibliometric analyses can contribute to the achievement of the SDGs in several ways. They can provide valuable insights to researchers, the public and private sectors, and policymakers on where gaps exist and where more attention is needed, typically by monitoring research trends, collaborations, etc. For example, bibliometric analyses can contribute to promoting interdisciplinary approaches in areas that require a holistic approach, such as the SDGs. Or, bibliometric analysis is of great importance in guiding and shedding light on future research.

In this study, the intersection of RS literature with the SDGs was investigated and bibliometric analysis methods were used. In the first step, RS articles associated with the SDGs were carefully filtered and a bibliometric analysis was performed on the retrieved articles. This analysis was used to identify which SDGs stand out in terms of their relevance to RS and which trends are prominent.

The gender distribution of the authors of the same articles was then analyzed and the articles were classified according to the SDGs to which they were related. This approach revealed how the field is structured in terms of gender diversity.

Finally, RS articles related to Global Goal 11, one of the SDGs that stood out in the first phase of the research in terms of its relationship with RS, were analyzed in detail. SDG 11 aims to achieve sustainable cities and communities, and the contributions of remote sensing in this context are critical at a broad level, from urban planning to urban infrastructure. This in-depth review highlighted the relevance of SDG 11 to remote sensing research, and a thematic framework was developed.

This multi-stage methodology (i.e., a multi-layered approach from the general to the specific) enabled a comprehensive assessment of the role of SDGs in remote sensing research and provided valuable insights for policymakers and researchers. In addition, the methodological choices of each stage of the study were consistent with the next stage, which had a positive impact on the credibility of the results.

3. METHODOLOGY

This chapter was divided into two parts. The first part describes the methodology applied to studies on the intersection of RS and SDGs, and the second part describes the methodology applied to studies on RS related to SDG 11.

3.1. Methodology for Analyzing Remote Sensing Research Related to the SDGs

The following three sections describe how the literature was searched, the documents filtered, and the additional analyses performed, respectively.

3.1.1. Strategy for Literature Search

In order to compile an appropriate dataset of relevant literature, the first step was to select keywords and use the Web of Science (WoS) Core Collection as a data repository. The search query was as follows:

> *TS=(("remote sensing" OR "Earth observation*") AND ("Sustainable Development Goal*"))*

where "TS" indicates a topic search that includes titles, abstracts, author keywords, and Keywords Plus in WoS documents (Ekmen & Kocaman, 2024). The asterisk "*" acted as a wildcard to include various combinations of characters, including no characters, in the search. This search was conducted for the period from January 1, 2016 to December 31, 2022, which is consistent with the start date of the SDGs. As of January 2, 2023, this method yielded a total of 410 documents (Ekmen & Kocaman, 2024).

3.1.2. Document Filtering Process and Bibliometric Analysis

This research used the Bibliometrix tool, which is commonly used in scientific studies to generate results through visualizations such as graphs and tables (see e.g., Alex et al., 2022; Bhargavan et al., 2023; Dange et al., 2023; Ghosh & Prasad, 2021; Lourenço et al., 2023; Ridwan et al., 2023; Singh et al., 2023). For this bibliometric analysis and data visualization, the relevant publication records were converted to plain text and uploaded to Biblioshiny, the web interface for the Bibliometrix R package developed by Aria and Cuccurullo (2017). Bibliometrix, which is part of the R programming language ecosystem (R Core Team, 2022), and its user interface, Biblioshiny, are characterized by a wide range of analysis functions that offer a wide range of different analysis methods (Table 3.1), as highlighted by Moral-Muñoz et al. (2020). Bibliometrix offers a distinctive feature that plots author productivity over time and also provides tools for calculating network structure statistics, such as average path length and centralization measures (Bales et al., 2020).

Science mapping analysis tools	TN	AN	RN	ON	E	P	BD	S	G	Visualization
Biblioshiny	■	■	■	■	■	■	■	■	■	Network, three-fields plot, wordcloud, tree map, historiograph, strategic diagram, evolution map and world map
Bibexcel	■	■	■	■		■			■	External software
CiteSpace	■	■	■	■		■	■		■	Tree ring, geospatial map
CitNetExplorer			■							Network
SciMAT	■	■	■	■	■	■				Strategic diagram, cluster network, overlapping map, evolution map
Sci^2 Tool	■	■	■	■			■		■	Temporal, geospatial map, topical, network
VOSviewer	■	■	■	■		■				Network, overlay, density

Table 3.1. Comparison of analysis and visualization options of some science mapping analysis tools (TN: Thematic Network, AN: Author Network, RN: Reference Network, ON: Other Networks, E: Evolution, P: Performance, BD: Burst Detection, S: Spectrogram, G: Geospatial) (adapted from: Moral-Muñoz et al., 2020).

For the sake of clarity, the documents were limited to English-language publications. While the WoS Core Collection database contains documents that could fall under multiple categories, such as data papers or early access articles, the study focused exclusively on documents that were strictly classified as research articles. This strict selection criterion resulted in a total of 308 articles being analyzed, reducing the number of sources from 174 to 120 and the number of authors from 2033 to 1581 (Ekmen & Kocaman, 2024). The methodology is presented as a flowchart in Figure 3.1.

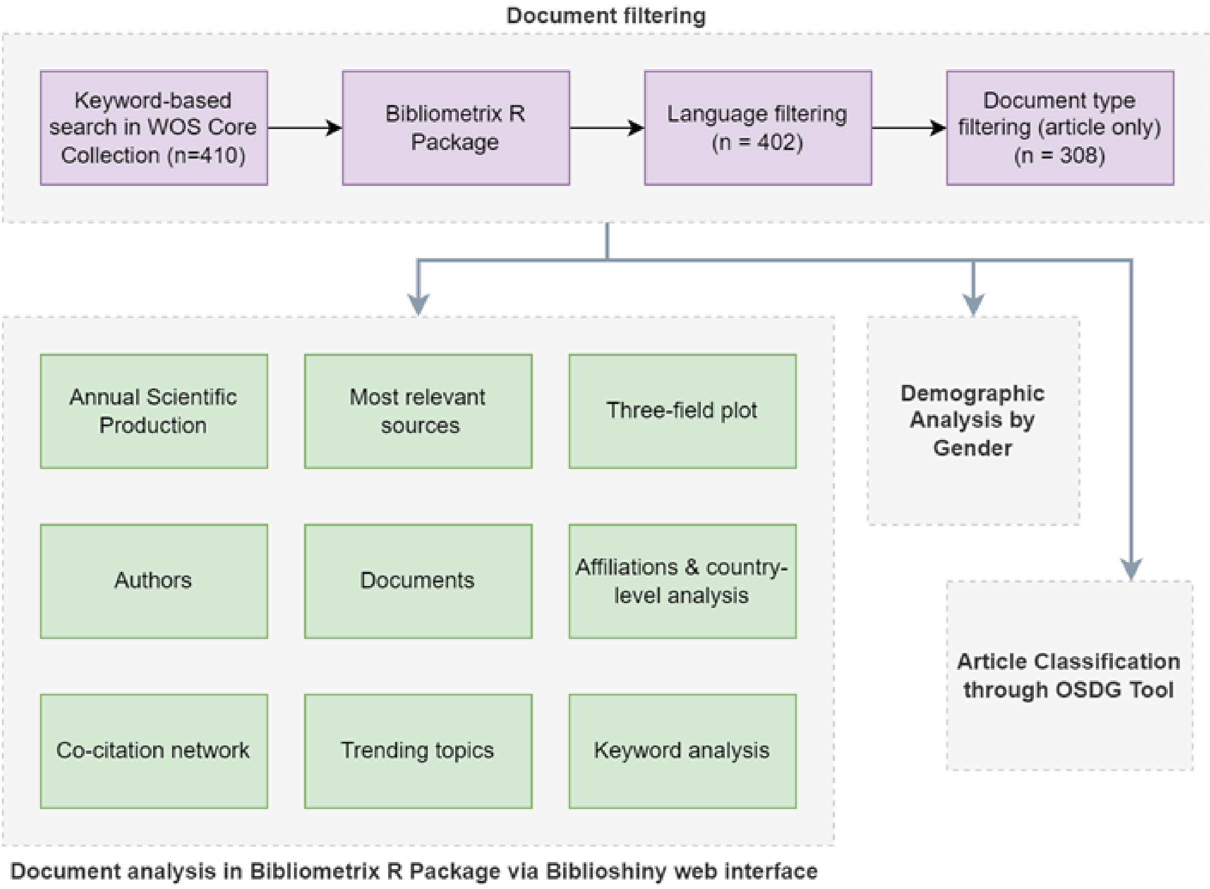

Figure 3.1. Flow diagram illustrating the methodology (modified from Ekmen & Kocaman, 2024).

While Biblioshiny, complemented by the Bibliometrix library, allows for various analysis configurations and visualizations, this part of the study focuses on the most important sources, authors, and their affiliations, and examines their interrelationships through co-citation networks and keyword analysis (Ekmen & Kocaman, 2024). The selected analyses and their brief descriptions are listed in Table 3.2. This table includes the adjustable parameters for each analysis (shown in italics), with the implemented values (shown in bold fonts).

Table 3.2. In-depth analysis and essential configuration options (modified from Ekmen & Kocaman, 2024).

Analysis	Significance	Options / Configurations
Annual Scientific production	CAGR of publications	$CAGR = ((\frac{EV}{BV})^{\frac{1}{n}} - 1)$ x 100 where EV = ending value BV = beginning value n = number of years
Sources	Most relevant journals	*Number of sources*: **20**
Three-field plot	Relationship among selected 3 metadata fields by a Sankey Diagram	*Fields* (authors, **affiliations**, **countries**, keywords, Keywords Plus, titles, abstract, **sources**, references, cites sources), *number of items:* **10**
Authors	Authors' production over time	*Number of authors:* **10**
Documents	Most local cited articles	*Number of documents:* **20**
Affiliations & countries	Most relevant affiliations	*Number of affiliations:* **20**

	Corresponding author's country	*Number of countries:* **25**
	Collaboration world map	*Min edges:* **2**
Trending topics	Trending terms	*Field* (Keywords Plus, author's keywords, titles, **abstracts**), *N-grams* (unigrams, **bigrams**, trigrams), *word minimum frequency:* **3**, *number of words per year:* **3**
Co-citation	Co-citation network of papers	*Field* (**papers**, authors, sources), *network layout* (**automatic layout**, circle, Fruchterman & Reingold, Kamada & Kawai, multidimensional scaling, Sphere, Star), *clustering algorithm* (none, edge betweenness, fast greedy, InfoMap, **leading eigenvalues**, Leiden, Louvain, Spinglass, Walktrap), *number of nodes:* **30**, *repulsion force:* **0.1**, *remove isolated nodes* (**yes**, no), *minimum number of edges:* **2**
	Co-citation network of journals	*Field* (papers, authors, **sources**), *network layout* (**automatic layout**, circle, Fruchterman & Reingold, Kamada & Kawai, multidimensional scaling, Sphere, Star), *clustering algorithm* (none, edge betweenness, fast greedy, InfoMap,

		leading eigenvalues, Leiden, Louvain, Spinglass, Walktrap), *number of nodes:* **30**, *repulsion force:* **0.1**, *remove isolated nodes* (**yes**, no), *minimum number of edges:* **2**
Keywords	Frequently-occurring author keywords by a word cloud	*Field* (Keywords Plus, **author's keywords**, titles, abstracts), *number of words:* **30** (then **24**)
	Co-occurrence network of author keywords	*Field* (Keywords Plus, **author's keywords**, titles, abstracts), *load a list of terms to remove* (**yes**, no), *load a list of synonyms* (**yes**, no), *network layout* (**automatic layout**, circle, Fruchterman & Reingold, Kamada & Kawai, multidimensional scaling, Sphere, Star), *clustering algorithm* (none, edge betweenness, fast greedy, InfoMap, leading eigenvalues, Leiden, Louvain, Spinglass, **Walktrap**), *normalization* (none, **association**, Jaccard, Salton, inclusion, equivalence), *node color by year* (yes, **no**), *number of nodes:* **24**, *repulsion force:* **0.1**, *remove isolated nodes* (**yes**, no), *minimum number of edges:* **2**

Annual scientific output is calculated based on compound annual growth rate (CAGR), which has been found to be superior to average annual growth rate (AAGR) because the latter ignores the effect of compounding, which can overestimate growth (Kim, 2018). CAGR reduces the effect of volatility (Collazzo & Taieb, 2015). Most relevant journals are limited to 20 given the total number of returned documents. The three-field plot visualizes the relationships between different parameters, and here affiliations, countries, and sources were preferred because this configuration provides interpretable results when limited to 10 items. The authors' production over time provides an overview of the continuity of research. The document analysis provides the most globally and locally cited articles. For the trending topics analysis, a word must have a frequency of at least 3 times per year to be listed in the analysis, and a maximum of 3 terms are listed per year (Ekmen & Kocaman, 2024).

The co-citation network (Small, 1973) and keyword analyses were based on consensus clustering, which aims to uncover the organization and buried relationships in complex networks (Lancichinetti & Fortunato, 2012). The co-citation network analysis performed here represents the clusters of articles or journals, and the eigenvector analysis (Newman, 2003) was preferred to obtain the consensus. However, the other methods offered in Biblioshiny, namely edge betweenness, fast greedy, InfoMap, Leiden, Louvain, Spinglass, and Walktrap, also offer similar accuracies and computational times (Yang et al., 2016). The keyword analysis, limited to 30 author keywords, creates a word tree map and a keyword co-occurrence network. These author keywords were then standardized for duplicates, and unique keywords were used for the word tree map (Ekmen & Kocaman, 2024). For the keyword co-occurrence network clustering, an algorithm called Walktrap, which measures vertex similarity on the basis of random walks (Pons & Latapy, 2006), was chosen. When making rankings such as top 20, top 25, etc., if there is additional item that has the same score as the last item listed, the one ahead in alphabetical order was ranked.

3.1.3. Additional Analyses on SDG-related Remote Sensing Articles

Additional analyses included the gender distribution of authors through the first and corresponding authors of articles, and the classification of articles according to the SDGs to which they are associated.

The Gender Distribution

The gender distribution was analyzed in for the publications on the RS/EO and SDGs by manually examining the first and corresponding authors in the returned documents. For each article, the full name of the first and corresponding author(s) and the publication date (as year) of the article were noted. The gender of each author was then determined through a detailed web search, which included an examination of their academic and institutional profiles, their professional profiles on platforms such as Google Scholar, ResearchGate, etc., and/or by considering their first names. Publicatios with authors whose gender could not be determined were not included in the statistics.

The Literature by each SDG

As a complement to the analysis and to find the relationship between the analyzed articles and each SDG, an artificial intelligence (AI) tool was used. The Open Source SDG (OSDG) tool (Pukelis et al., 2020) is a unique initiative that addresses SDG-related uncertainties through a user-friendly application, and supports the identification and classification of SDG-related content (Pukelis et al., 2022). The abstract of each article was analyzed using the OSDG tool and linked to up to 3 SDGs (Ekmen & Kocaman, 2024). The results are presented in Section 5.1.

3.2. Methodology for Analyzing Remote Sensing Research Related to SDG 11

The following two sections describe how the literature was searched and the documents filtered, respectively

3.2.1. Strategy for Literature Search

The keyword selection and query generation process is shown in Figure 3.2. The keyword selection proces s was organized into 4 major conceptual categories called clusters. The detailed descriptions of each cluster are as follows:

- Cluster 1 (or Cluster A): It includes the textual content of SDG 11.
- Cluster 2 (or Cluster B): It contains the terms city, human settlement, and adjective and noun synonyms for city.
- Cluster 3 (or Cluster C): It covers the terms RS and EO.
- Cluster 4 (or Cluster D): It includes different ways of naming SDG 11.

To derive Cluster A, the words that occur in the text of SDG 11 (in the goal, targets and indicators of SDG 11) were scanned and proper words were extracted. Cluster B contained the words such as "city," "human settlement," and adjective and noun synonyms for city (Collins English Thesaurus, 2024). Cluster C consisted of the terms "remote sensing" and "Earth observation". Ultimately, cluster D was generated, which included different ways of naming SDG 11. By doing so, different routes to the relevant articles were designed with a systematic approach (Ekmen & Kocaman, 2023).

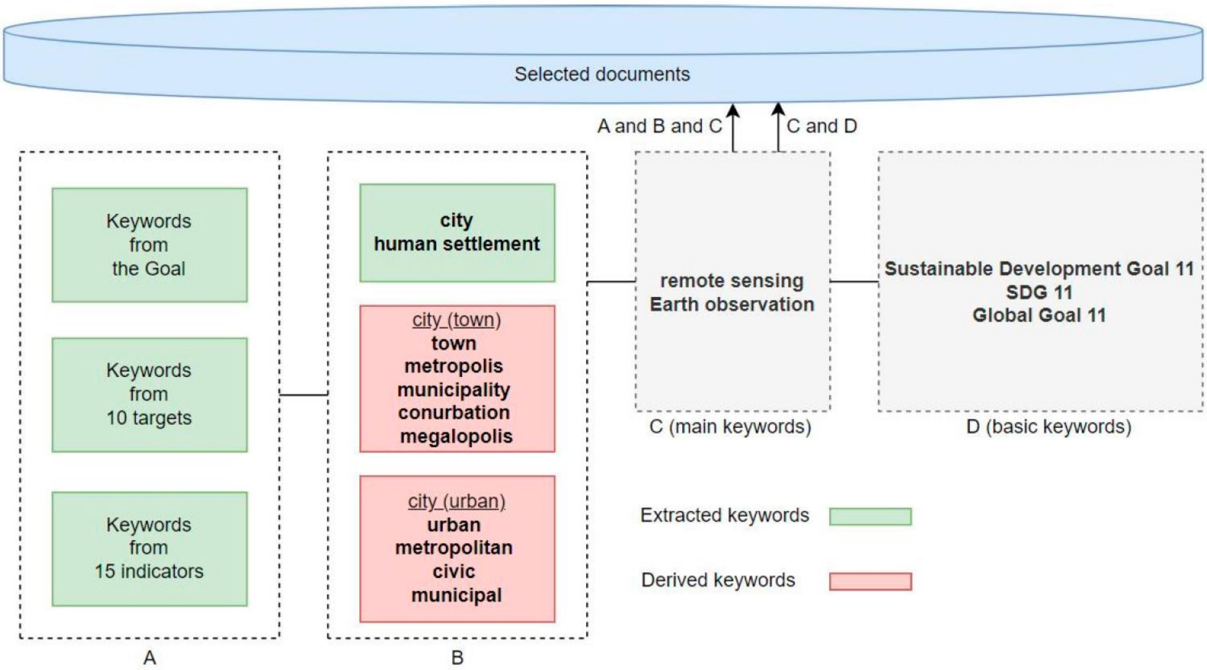

Figure 3.2. Query generation process (Ekmen & Kocaman, 2023).

In this systematic approach, search terms were distinguished by categorizing them into clusters. The search strategy involved combining Clusters A, B, and C. In addition, terms related to RS with SDG 11 and its various expressions, which are clusters C, D, were grouped. The two cluster groups were then related to each other and to each other using Boolean operators (Ekmen & Kocaman, 2023). The asterisk "*" as a wildcard, as used in Section 4.1.1, and the question mark "?" to account for variations in the spelling of "urbanization" in American and British English. As a result, the search query is structured in the following way (Ekmen & Kocaman, 2023):

> *TS=(((“inclusive” OR “safe” OR “resilient” OR “sustainable” OR “housing” OR “basic service*” OR “slum*” OR “transport” OR “road safety” OR “urbani?ation” OR “planning” OR “management” OR “cultural heritage” OR “natural heritage” OR “disaster*” OR “environmental impact” OR “air quality” OR “waste” OR “green space*” OR “public space*” OR “national development” OR “regional development” OR “policy” OR “policies” OR “climate change” OR “Sendai Framework” OR “population” OR “informal settlement*” OR “land consumption” OR “direct participation” OR “infrastructure” OR “fine particulate matter” OR “built-up area” OR “open space” OR “territorial development”) AND (“city” OR “cities” OR “human*

settlement" OR "town*" OR "metropolis*" OR "municipality" OR "municipalities" OR "conurbation*" OR "megalopoli*" OR "urban" OR "metropolitan" OR "civic" OR "municipal") AND ("remote sensing" OR "Earth observation*")) OR (("remote sensing" OR "Earth observation*") AND ("Sustainable Development Goal 11" OR "SDG 11" OR "Global Goal 11")))*

3.2.2. Document Filtering Process and Bibliometric Analysis

In bibliometric research, filtering data is critical to improving its quality and accuracy. This process leads to more reliable and robust results that are useful to a wide audience, from general readers to scholars. In this section, four data filters were applied (Ekmen & Kocaman, 2023). Field searching, document filtering, and date filtering were part of the data extraction from the WoS Core Collection database. A comprehensive search of topic terms (including title, abstract, author keywords, and Keywords Plus) across the entire dataset was performed to ensure a relevant and reliable dataset, avoiding documents unrelated to the topic (Ekmen & Kocaman, 2023). Since the SDGs were launched on January 1, 2016 (McIntyre, 2018), the analysis spanned from this date to June 30, 2023. The records from WoS were downloaded as a single plain text file on August 8, 2023, containing 7242 articles.

Upon uploading a plain text file to Biblioshiny, its features were used to filter the data by language and document type (again). The focus was narrowed to include only those documents that were strictly classified as articles in English, without any other categorizations. This filtering process resulted in a selection of 6820 articles for analysis, reducing the number of sources from 1090 to 942 and the number of authors from 21,134 to 20,076 (Ekmen & Kocaman, 2023). This large volume of data allowed for a detailed and scientific bibliometric analysis.

The yearly growth of scientific publications is measured by the CAGR. The 20 articles with the most local citations (which counts citations within a specific group, in this case the 6820 articles) were listed under the heading of most relevant articles. Additionally, the top 20 most prolific journals were also highlighted. These restrictions help to keep the focus, as too many entries might dilute the central theme, while too few might miss important research contributions. In terms of regional analysis, the study examined the number of articles per corresponding author's country and evaluated both single country publications (SCPs) and multi country publications (MCPs), which address scientific collaboration between different nations.

In the course of conceptual analysis, specific parameters were set: the number of words per document was set to 250, the minimum clustering frequency (per thousand documents) was set to 5, the number of labels was limited to 3, and the Walktrap clustering algorithm was chosen (Ekmen & Kocaman, 2023). The underlying principle of the Walktrap algorithm (Pons & Latapy, 2006) is based on the idea that random walks over shorter distances are more likely to stay within the same cluster (Lee et al., 2020). The thematic map, influenced by density and centrality metrics, uses the size of bubbles to represent the volume of publications (Rey-Álvarez, 2022). Callon's centrality measures the strength of a topic's connections to other communities, indicating its importance in the overall collection, while density evaluates the internal strength of a community, reflecting the evolution of the topic (Yu et al., 2021). This thematic map shows the strength of links between all the author keywords that define the research topic, providing a visual representation of density (Mumu et al., 2021).

During the keyword analysis phase, the first step was to examine the cumulative growth of the top 20 author keywords from year to year. Word clouds were then created using Keywords Plus terms and those derived from abstracts. Word clouds provide a visual summary of content, facilitating quick understanding without overwhelming the reader, and serve as an initial screening tool for large amounts of textual data (DePaolo & Wilkinson, 2014).

4. RESULTS

This chapter was divided into two sections. The first section presents the results of the analysis of RS studies related to the SDGs, and the second section presents the results of the analysis of RS studies specifically related to SDG 11.

4.1. Results of the Analysis of Remote Sensing Research in Relation to the SDGs

In this section, the findings of SDG-related RS studies are presented in detail under the relevant subheadings.

4.1.1. Overview of the Data used for the Analysis of Remote Sensing Research in Relation to the SDGs

Figure 4.1 presents key bibliometric data details. An overview of the data shows that during the period under review, 1581 authors from 120 different sources (journals) contributed to this research area. The dataset includes 8 single-author documents, with an average of 6.01 co-authors per document. In terms of citations, each document has an average of 14.21 citations, reflecting the popularity of the research topic among scholars. In addition, the total number of Keywords Plus and author keywords is 955 and 1206, respectively. A growing trend with a CAGR of 69.54% is an indicator of the growing interest of researchers (Ekmen & Kocaman, 2024).

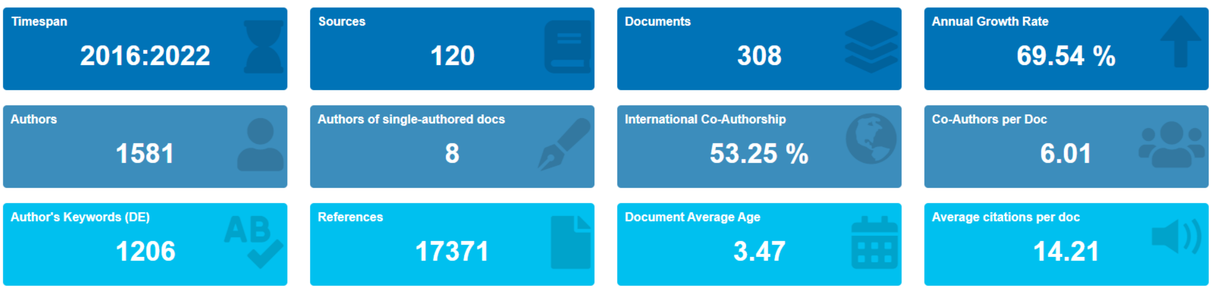

Figure 4.1. Overview of bibliometric data.

4.1.2. Analysis of Scientific Production by Year

Figure 4.2 shows a steady increase in the publication of articles on RS studies related to the SDGs over the period from 2016 to 2022. Initially, there are only 4 articles in 2016 and 2017. A significant increase is observed in subsequent years, with the number rising to 23 in 2018, 40 in 2019, 56 in 2020, and escalating further to 86 in 2021. The number peaks at 95 articles at the end of 2022, demonstrating a consistent upward trend in research interest and output.

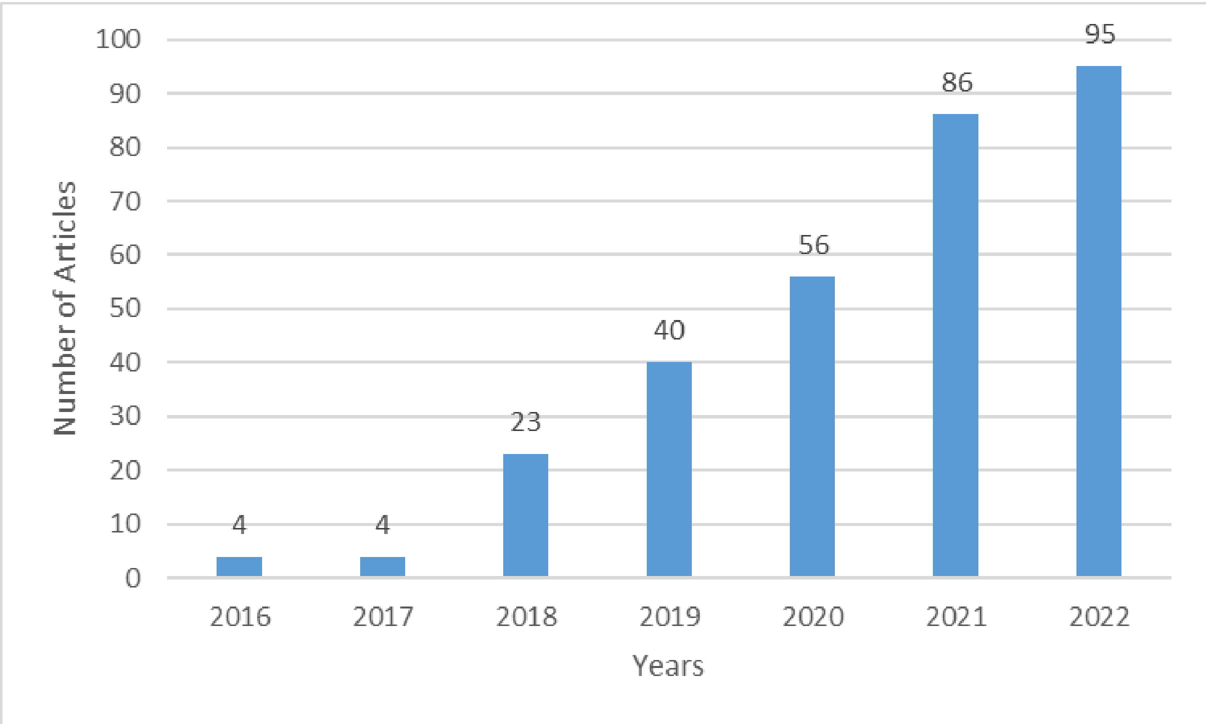

Figure 4.2. Scientific production by year (Ekmen & Kocaman, 2024).

4.1.3. Most Relevant Journals

Table 4.1 lists the top 20 journals that have published the most articles on SDG-related RS research. *Remote Sensing* stands out with 55 articles, followed by *Sustainability* with

25 articles. *Remote Sensing of Environment* has published 19 articles and *ISPRS International Journal of Geo-Information* has published 11 articles. Both *International Journal of Applied Earth Observation and Geoinformation* and *International Journal of Digital Earth,* have contributed 10 articles each, as has *Science of the Total Environment*. *Environmental Monitoring and Assessment*, *Environmental Science & Policy*, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, and *Journal of Environmental Management* each published 6 articles within the specified time period.

Table 4.1. Most relevant journals.

Journals	**N. of Articles**
Remote Sensing	55
Sustainability	25
Remote Sensing of Environment	19
ISPRS International Journal of Geo-Information	11
International Journal of Applied Earth Observation and Geoinformation	10
International Journal of Digital Earth	10
Science of the Total Environment	10
Environmental Monitoring and Assessment	6
Environmental Science & Policy	6
IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	6
Journal of Environmental Management	6

Big Earth Data	5
Environmental Research Letters	5
Geo-Spatial Information Science	5
Ecological Indicators	3
Habitat International	3
ISPRS Journal of Photogrammetry and Remote Sensing	3
Land	3
Land Use Policy	3
Acta Astronautica	2

Bradford's Law is often used in bibliometric studies to evaluate the publication performance of journals (Kousis & Tjortjis, 2021). As can be seen in Figure 4.3, most literature on the subject comes from a handful of core journals. These journals are the following respectively: *Remote Sensing*, *Sustainability*, *Remote Sensing of Environment*, and *ISPRS International Journal of Geo-Information*.

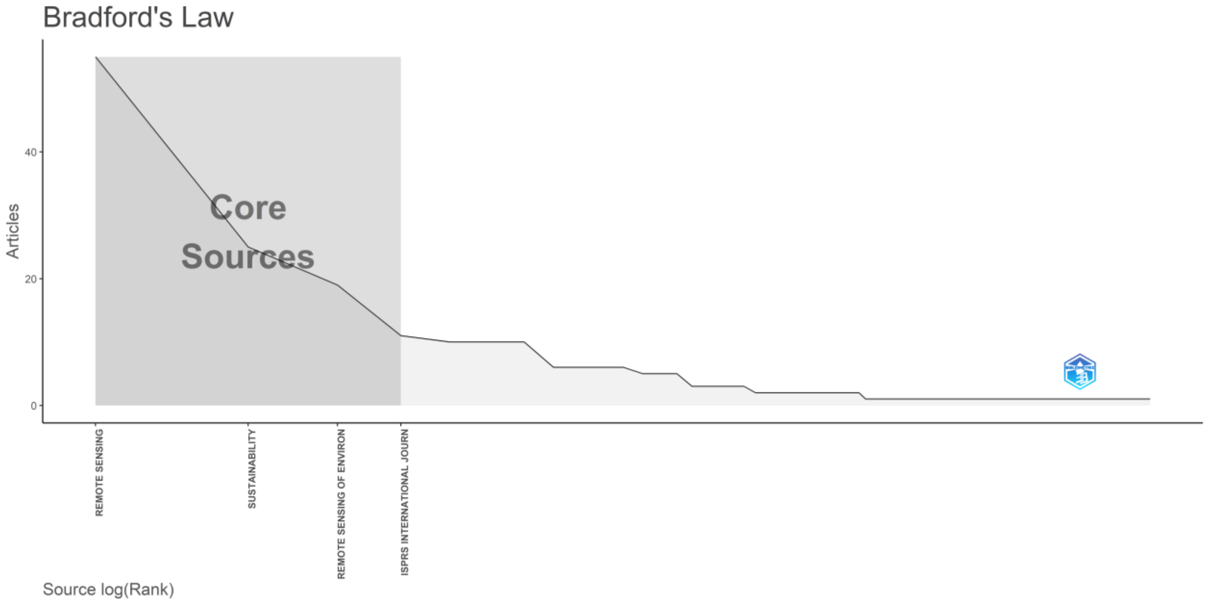

Figure 4.3. Bradford's Law.

4.1.4. Three-field Plot

In Biblioshiny, the three-field plot function is a tool for visually assessing the connections between various elements, including countries, affiliations, etc. and provide an in-depth view of their interrelationships (Yaqoub et al., 2023). A large number of bibliometric studies have used three-field plots (Dzogbewu et al., 2023; Gupta & Chakravarty, 2021; Jain, 2022; Koo, 2021; Kumar et al., 2021; Linnenluecke et al., 2020; Mallia et al., 2023). Figure 4.4 uses a three-field plot to illustrate the relationships between countries, affiliations, and journals. The size of the rectangular nodes in the plot indicates the frequency of occurrence of a particular country, affiliation, or journal. The width of the gray lines connecting the nodes reflects the volume of the connections. This figure shows that China has the highest number of connections, followed by the USA. The left column of the plot clearly shows the dominance of Chinese institutions. Regarding the journals on the right, the main contributing countries to the leading journal (*Remote Sensing*) are China, the USA, and Germany, in descending order.

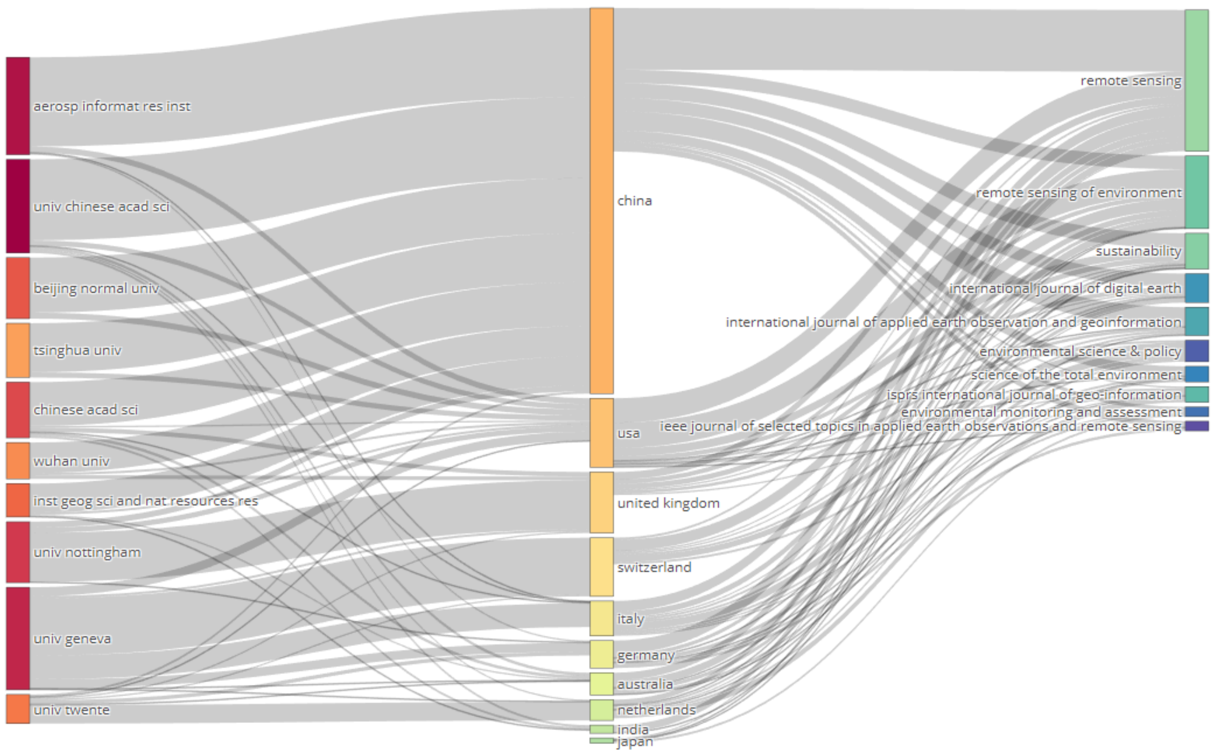

Figure 4.4. The three-field plot of affiliations (on the left), countries (in the middle), and journals (on the right) (Ekmen & Kocaman, 2024).

5.1.5. Top Contributing Authors

The scientific productivity of the top 10 authors in the topic over time is shown in Figure 4.5. Each circle correlates with their number of articles and total citations per year. The presence of circles along an author's linear line indicates at least one publication on the topic in that year. Larger circles indicate more articles published by the author in that year, while different shades represent total annual citations. Darker shades indicate more citations and lighter shades indicate fewer citations. Furthermore, larger distances between circles on an author's line indicate longer intervals since their last publication on the topic. The figure shows that Gregory Giuliani has the highest number of publications, with 12 publications and Stefano Nativi has the longest publication timeline, with 7 publications from 2016 to 2022.

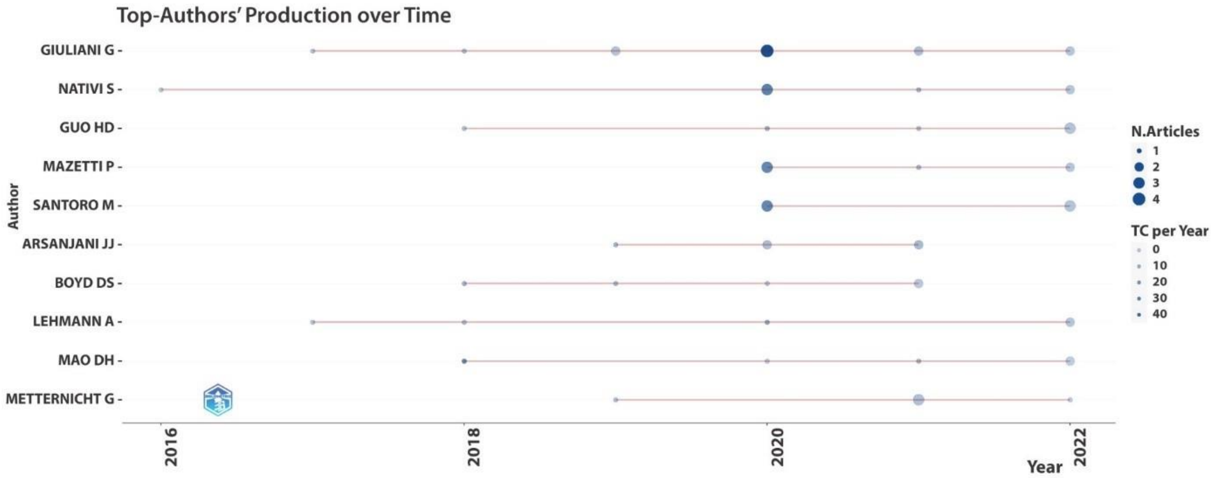

Figure 4.5. Authors' production over time (Ekmen & Kocaman, 2024).

4.1.6. Most Cited Articles

The top 20 articles, ranked by the number of local citations, are shown in Table 4.2. A local citation (LC) counts how often an article is cited by one of the other 307 articles in the database, whereas the global citation (GC) refers to the total number of WoS citations for an article. As shown in the same table, the ranking of articles based on GC does not align with the ranking of articles based on LC.

Table 4.2. Most locally cited articles.

Articles	**Year**	**LC**	**GC**	**LC/GC Ratio %**
ANDERSON K, 2017, GEO-SPAT INF SCI	2017	39	172	22,67
MELCHIORRI M, 2019, ISPRS INT J GEO-INF	2019	14	65	21,54
NATIVI S, 2020, INT J DIGIT EARTH	2020	10	31	32,26
GIULIANI G, 2020, INT J APPL EARTH OBS	2020	8	47	17,02
WANG YC, 2020, REMOTE SENS-BASEL	2020	8	36	22,22
ANDRIES A, 2019, SUSTAIN DEV	2019	7	34	20,59
MASO J, 2020, INT J DIGIT EARTH	2020	7	23	30,43
KUSSUL N, 2020, INT J DIGIT EARTH	2020	7	33	21,21
MUDAU N, 2020, SUSTAINABILITY-BASEL	2020	7	18	38,89
WATMOUGH GR, 2019, P NATL ACAD SCI USA	2019	6	63	9,52
COCHRAN F, 2020, REMOTE SENS ENVIRON	2020	6	34	17,65
WHITCRAFT AK, 2019, REMOTE SENS ENVIRON	2019	5	37	13,51
ZHU Z, 2019, REMOTE SENS ENVIRON	2019	5	134	3,73
SIMS NC, 2019, ENVIRON SCI POLICY	2019	5	47	10,64

AVTAR R, 2020, ENVIRON MONIT ASSESS	2020	5	33	15,15
ESTOQUE RC, 2021, HABITAT INT	2021	5	26	19,23
LEHMANN A, 2017, SUSTAINABILITY-BASEL	2017	4	9	44,44
BRAUN D, 2018, ECOL INDIC	2018	4	37	10,81
MAO DH, 2018, LAND DEGRAD DEV	2018	4	164	2,44
ANDRIES A, 2019, SUSTAINABILITY-BASEL	2019	4	18	22,22

4.1.7. Analysis of Contributions by Affiliation and Country

Table 4.3 highlights the top 20 academic institutions associated with the authors, with a dominating presence of Chinese institutions. Table 4.4 lists the top 25 countries by country of corresponding author. This list shows both single country publications (SCPs) and multi country publications (MCPs) separately in one list. China leads with 80 articles, of which 46 are SCPs and 34 are MCPs. China is followed by the USA with 36 articles, of which 16 are SCPs and 20 are MCPs. Italy and the United Kingdom contribute 20 articles. Italy has 11 SCPs and 9 MCPs, while the United Kingdom has 7 SCPs and 13 MCPs. In particular, France (MCP ratio of 1), Switzerland (MCP ratio of 0.8), Sweden (MCP ratio of 0.8), and Austria (MCP ratio of 0.75) stand out for their high level of international collaborations.

Table 4.3. Most relevant affiliations (Ekmen & Kocaman, 2024).

Affiliation	**N. of Articles**
UNIV CHINESE ACAD SCI	27
AEROSP INFORMAT RES INST	25
UNIV GENEVA	24

UNIV NOTTINGHAM	16
CHINESE ACAD SCI	15
BEIJING NORMAL UNIV	13
INST GEOG SCI AND NAT RESOURCES RES	10
UNIV TWENTE	10
WUHAN UNIV	10
TSINGHUA UNIV	9
HENAN UNIV	8
UNIV SOUTHAMPTON	8
UNIV ZURICH	8
XINJIANG UNIV	8
ARISTOTLE UNIV THESSALONIKI	7
INT RES CTR BIG DATA SUSTAINABLE DEV GOALS	7
UNIV MARYLAND	7
BEIJING FORESTRY UNIV	6
COLORADO STATE UNIV	6
NORTHEAST INST GEOG AND AGROECOL	6

Table 4.4. Corresponding author's country.

Country	**Articles**	**SCP**	**MCP**	**MCP Ratio**
China	80	46	34	0,425

USA	36	16	20	0,556
Italy	20	11	9	0,45
United Kingdom	20	7	13	0,65
Switzerland	15	3	12	0,8
Australia	13	6	7	0,538
Netherlands	12	4	8	0,667
Germany	10	6	4	0,4
India	9	7	2	0,222
Japan	7	2	5	0,714
Denmark	6	3	3	0,5
Sweden	5	1	4	0,8
Austria	4	1	3	0,75
Greece	4	2	2	0,5
Portugal	4	2	2	0,5
Spain	4	1	3	0,75
Brazil	3	2	1	0,333
Canada	3	1	2	0,667
Egypt	3	2	1	0,333
France	3	0	3	1
Iran	3	1	2	0,667
South Africa	3	2	1	0,333

Thailand	3	2	1	0,333
Ghana	2	2	0	0
Malaysia	2	1	1	0,5

International research partnerships are shown on a world map (Figure 4.6), with red lines connecting two countries that collaborate on publications, indicating that the USA and China have the strongest scientific partnership. The map uses shades of blue to represent the volume of publications. Darker shades indicate a higher number of publications.

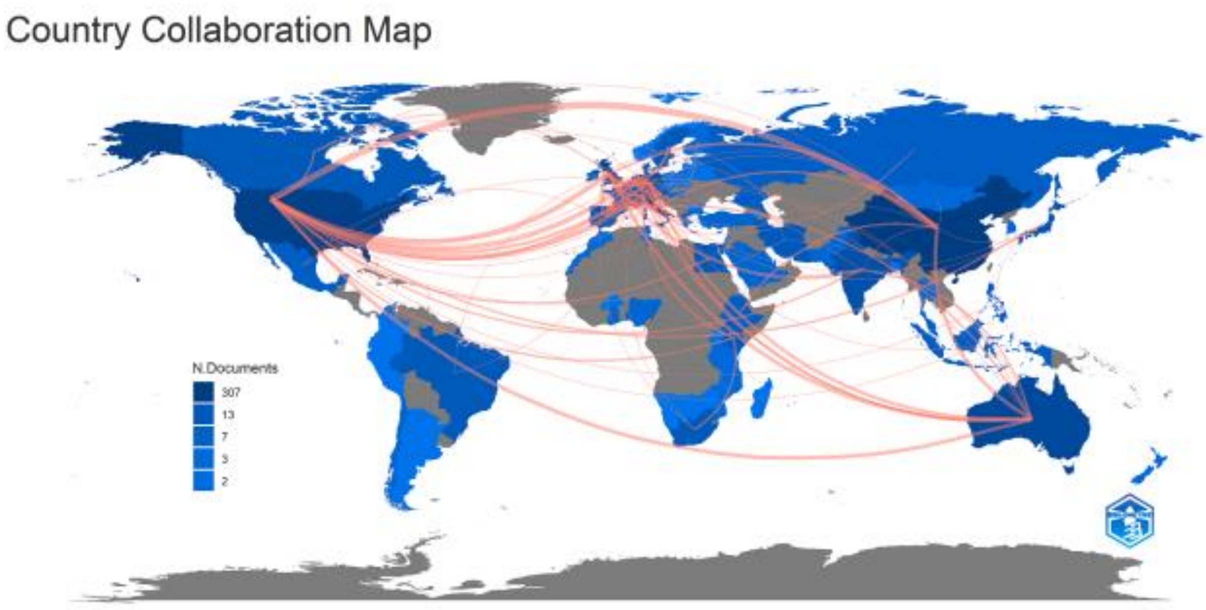

Figure 4.6. World map of collaboration (Ekmen & Kocaman, 2024).

4.1.8. Co-citation Network

The co-citation network of articles is shown in Figure 4.7, with clusters distinguished by color. Articles, shown as colored circles, are connected when they are cited together within a third document. The size of the circle reflects the centrality of the article within its cluster, with closer proximity indicating a higher frequency of co-citation. Likewise, Figure 4.8 displays the co-citation network of journals, derived from an analysis where two documents from different journals are cited in the same third document. For the sake of clarity, the number of nodes in both figures has been limited to 30.

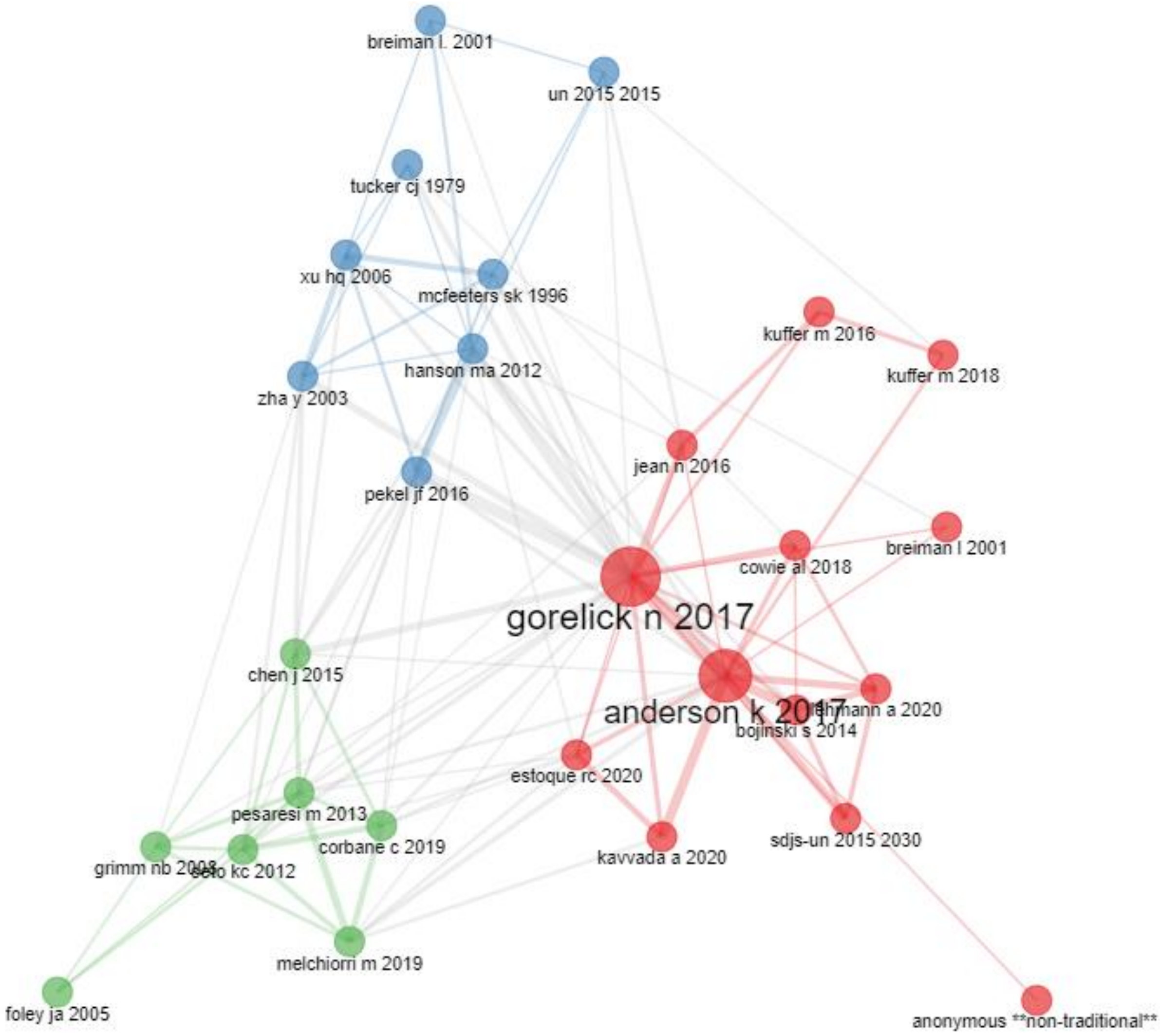

Figure 4.7. Co-citation network of articles (Ekmen & Kocaman, 2024).

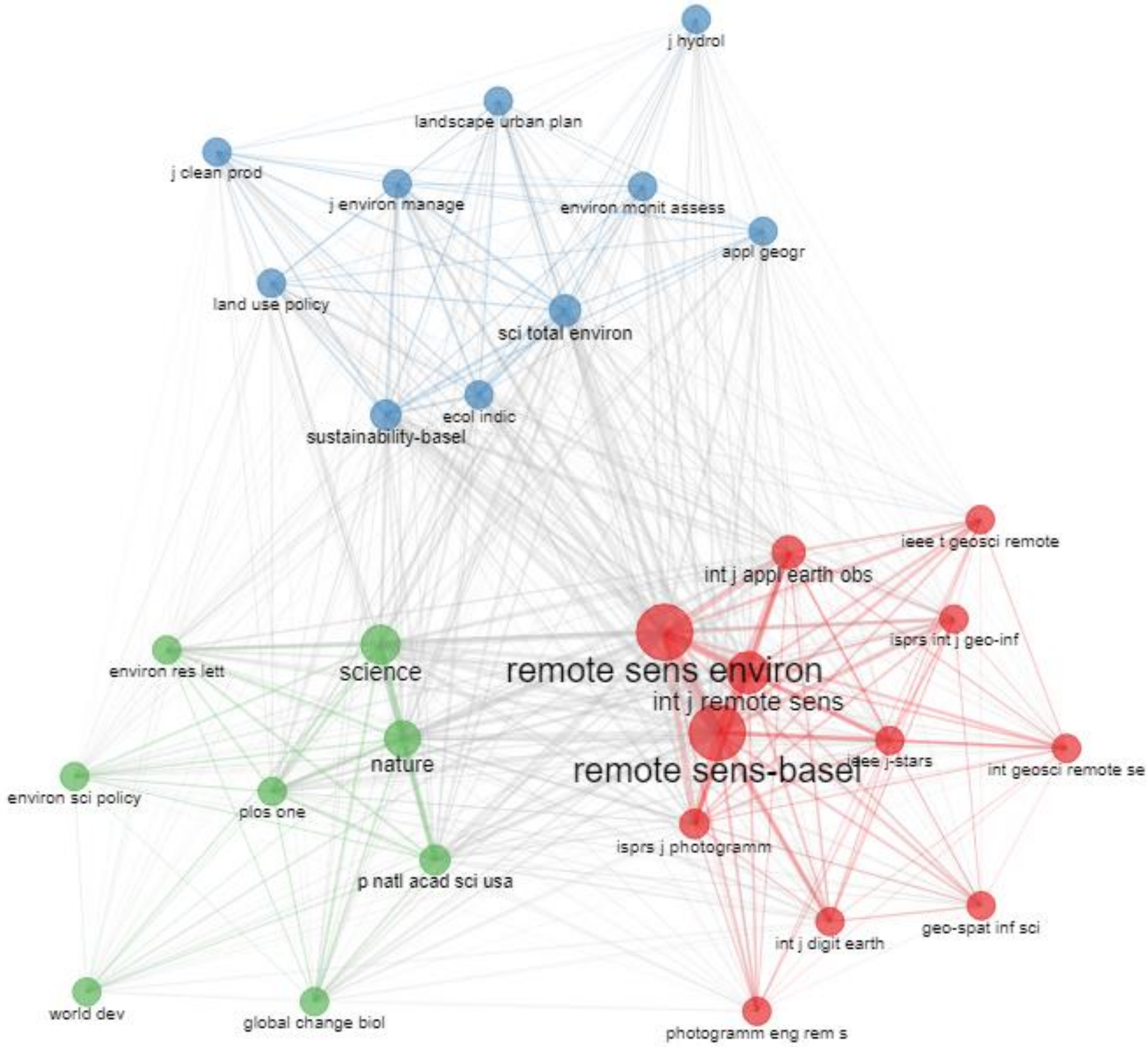

Figure 4.8. Co-citation network of journals (Ekmen & Kocaman, 2024).

4.1.9. Trending Topics

The trending topics were identified by analyzing word frequency, with a threshold of at least 3 occurrences per year in the abstracts, and up to 3 terms were highlighted for each year. Upon ignoring the keywords and their variants (such as development goals), the most common terms were identified as land degradation and ecosystem services, appearing 57 and 45 times, respectively, as shown in Figure 4.9. Other terms frequently mentioned in the abstracts include EO data (39 times) and satellite imagery (17 times). It has been observed that carbon storage and ecological quality have emerged as new trending topics, and it is expected that these areas will receive increasing focus in future research.

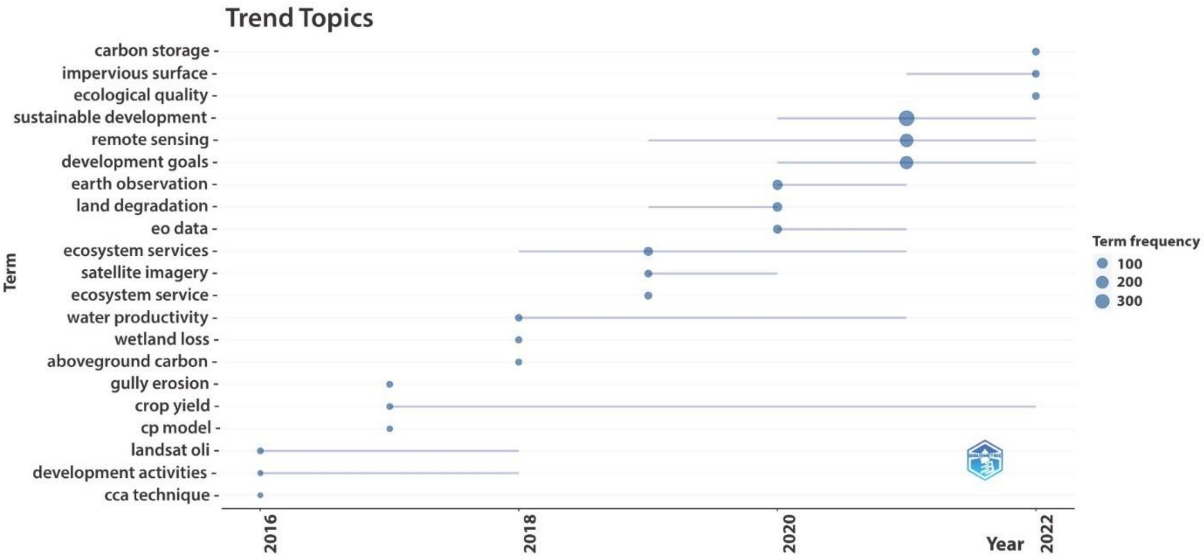

Figure 4.9. Trending topics (Ekmen & Kocaman, 2024).

4.1.10. Keyword Analysis

The process was initiated by identifying the top 30 most common author keywords. These keywords were then standardized to eliminate duplicates, and unique terms were selected to create a word cloud. In addition, the numbers 1 and 3, which are included in the keywords but have no independent meaning, were excluded. The analysis was limited to the 24 most frequent author keywords, with the top 5 being Sustainable Development Goals (108), Remote Sensing (92), Earth Observation (33), Sustainable Development (19), and Landsat (18). Figure 4.10 illustrates the diversity of these keywords, highlighting research focus areas such as urbanization, land degradation, deforestation, food security, land use, and SDG 11. The results also highlight the growing reliance on cloud platforms for data storage and processing, such as Google Earth Engine, as well as the accessibility of free EO data sources, such as Landsat and Sentinel-2 satellites, and tools, such as geographic information systems (GIS) and machine learning.

Figure 4.10. Word cloud.

The analysis concluded with the visualization of the co-occurrence network, which illustrates the connections between the previously identified top 23 out of 24 author keywords, as shown in Figure 4.11. These keywords were organized into clusters, with the network revealing 4 distinct groups that can be described in the following manner:

- Cluster 1 (blue): Sustainable Development Goals, Remote sensing, Landsat, climate change, urbanization, GIS, sustainability, machine learning, Sentinel-2, deforestation, ecosystem services, food security, protected areas, and China.
- Cluster 2 (green): Earth observation, sustainable development, land degradation, and big Earth data.
- Cluster 3 (red): Google Earth Engine, land cover, and land use.
- Cluster 4 (violet): Essential variables and indicators.

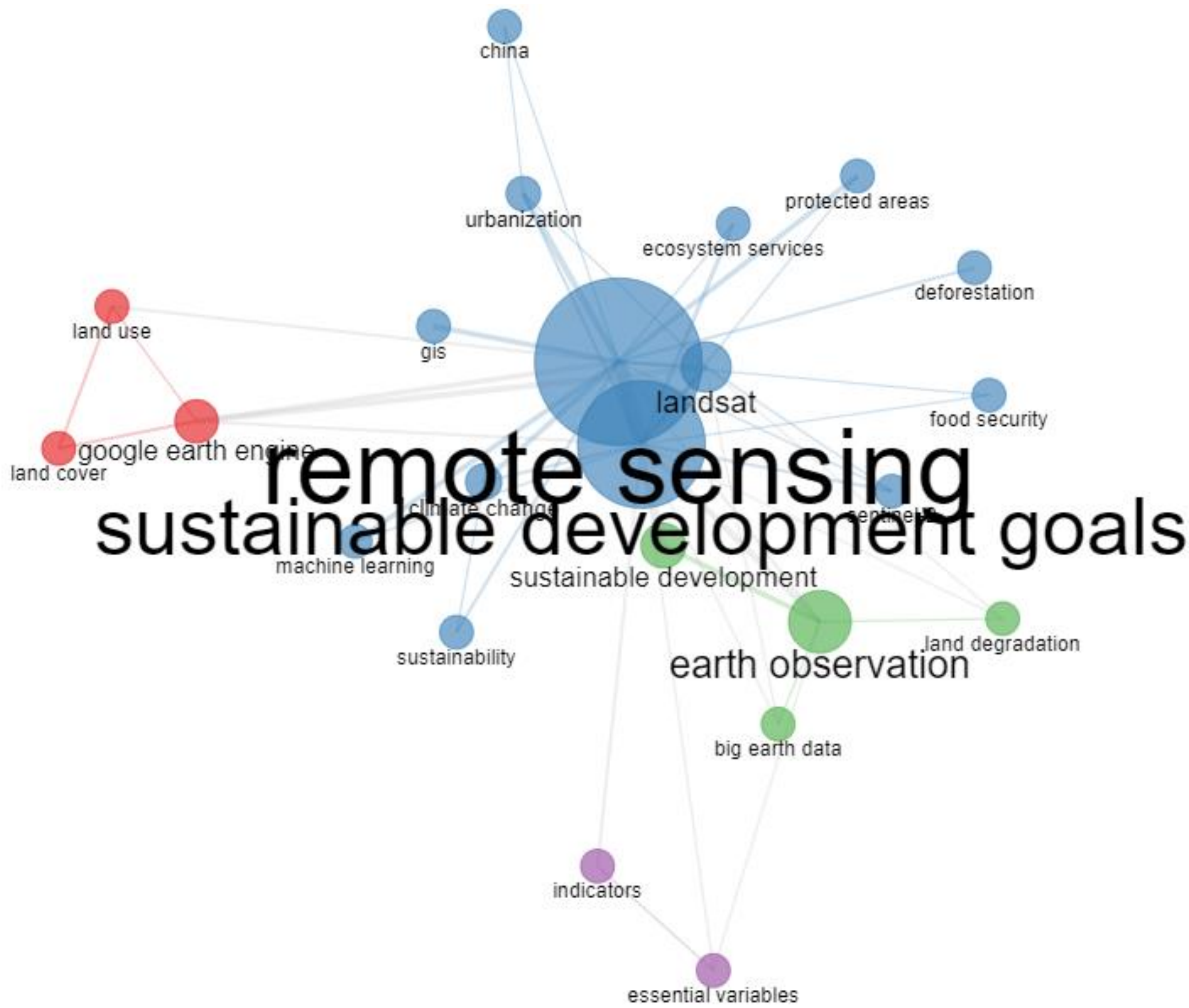

Figure 4.11. Co-occurrence network of author keywords (Ekmen & Kocaman, 2024).

4.1.11. Analysis of Gender Distribution

The first and corresponding authors of the articles reviewed here were analyzed for gender distribution. The gender of the first author could be determined for 297 of the 308 articles. During the study period, women represented 35% of all first authors (Figure 4.12). The number of articles with female first authors showed an apparent increasing trend, while the proportion of female first authors fluctuated over time. Female researchers accounted for 50%, 25%, 32%, 45%, 33%, 30%, and 37% of all first authors in 2016, 2017, 2018, 2019, 2020, 2021, and 2022, respectively. The results shown in Figure 4.12 indicate that although the number of articles co-authored by female researchers has increased in parallel with the increase in the total number of publications, male dominance in the field continues.

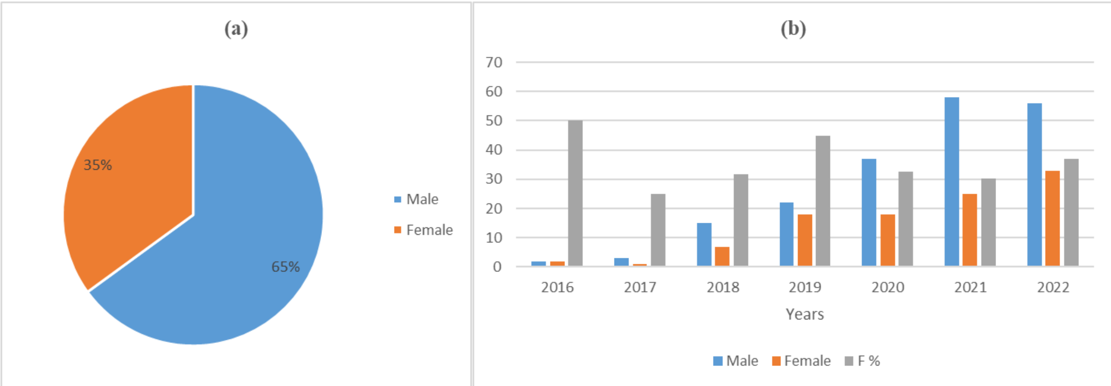

Figure 4.12. Gender distribution of first authors (a) overall, (b) per year.

When the corresponding authors were analyzed, it was found that the gender gap widened even further. Out of a total of 325 corresponding authors, only 29% of the 316 corresponding authors whose determined gender were female (Figure 4.13). The percentage of women among all corresponding authors by year was 25% in 2016 and 2017, 42% in 2018, 42.5% in 2019, 26% in 2020 and 2021, and 25% in 2022. Again, the number of female corresponding authors shows an increasing trend over time.

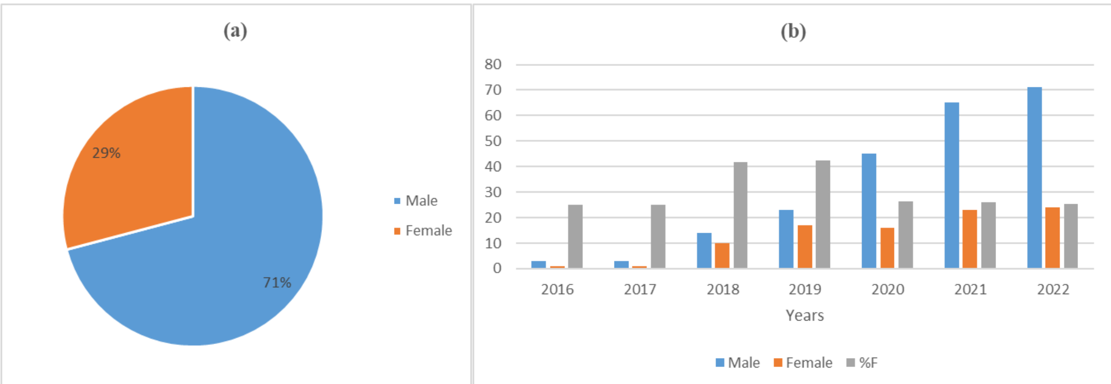

Figure 4.13. Gender distribution of corresponding authors (a) overall, (b) per year.

4.1.12. Classifying Articles Using the OSDG Tool

The OSDG tool successfully linked 273 articles to the SDGs, identifying SDG 15 and SDG 11 as the dominant themes, as shown in Figure 4.14. The analysis (Ekmen & Kocaman, 2024) revealed significant overlap, with many articles that addressed SDG 15 also addressing SDG 11. This assessment highlighted that SDG 11 was the most frequently cited SDG in isolation, rather than paired with another SDG. The finding shows that 18% of the papers linked SDG 11 and SDG 15 together, 5% linked SDG 6 and SDG 15, 4% linked SDG 13 and SDG 15, and 2% linked SDG 11 and SDG 13. Almost 70% of all greenhouse gas emissions come from urban areas (UN Habitat, 2018). This is significant in terms of showing the relationship between cities and SDG 13 (Climate Action).

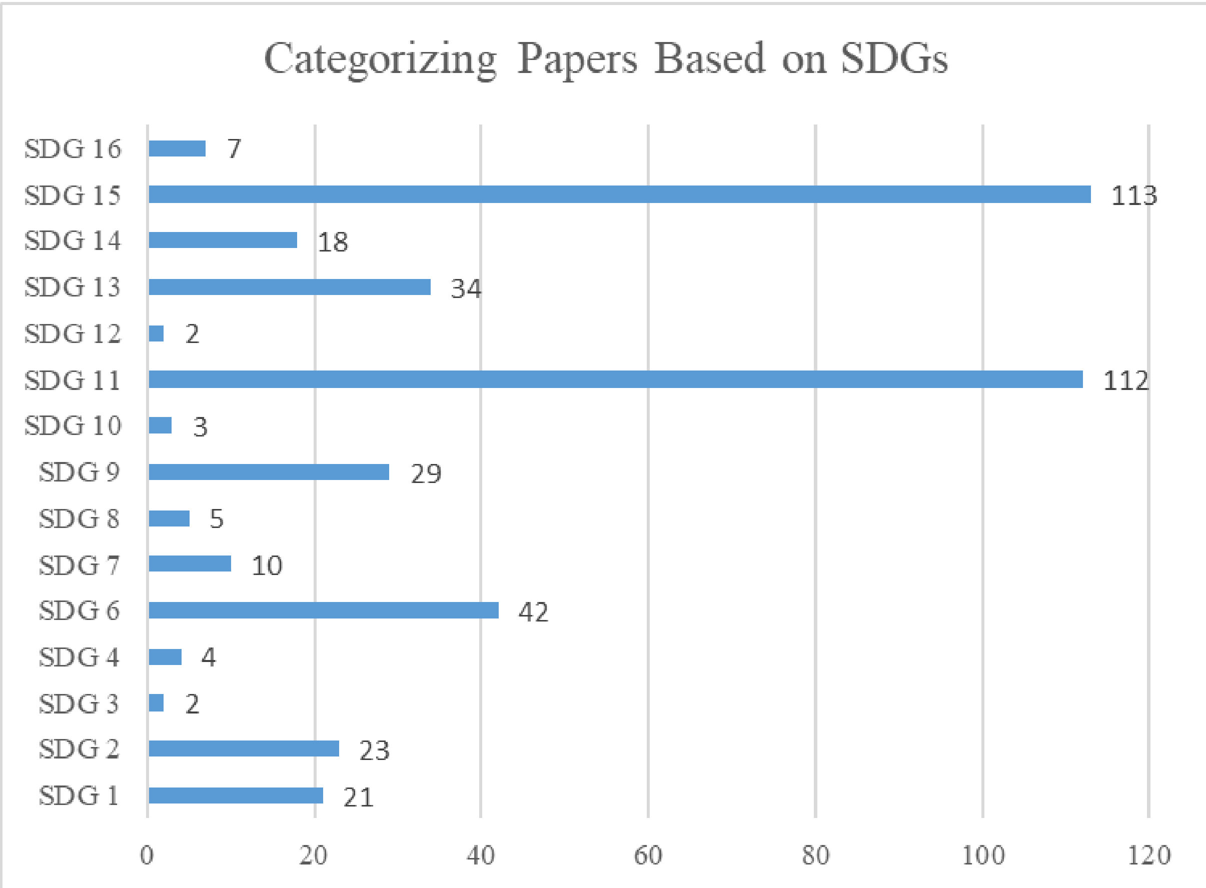

Figure 4.14. Number of articles according to the SDGs (Ekmen & Kocaman, 2024).

4.2. Results of the Analysis of Remote Sensing Research in Relation to SDG 11

In this section, the findings of SDG 11-related RS studies are presented in detail under the relevant subheadings.

4.2.1. Overview of the Data used for the Analysis of Remote Sensing Research in Relation to SDG 11

Figure 4.15 summarizes the key metrics of the bibliometric data on SDG 11-related remote sensing research. During the period from January 1, 2016 to June 30, 2023, the analysis shows that 20,076 authors have contributed to the field. This includes 189 authors who authored single-authored documents. The dataset contains 211 single-authored documents. On average, documents have 4.84 co-authors, suggesting a high level of collaboration among researchers. International co-authorship accounts for nearly 32% of the papers, indicating global collaboration in advancing SDG 11 through remote sensing.

In terms of keywords, the investigation identified 7432 keywords through Keywords Plus and 15,420 through author keywords. This rich keyword pool reflects the multidisciplinary nature of the research. An average citation per document of 15.39 underscores the dynamic and impactful contributions of the academic community to the achievement of SDG 11.

A remarkable increase of 22.90% in research publications can be seen when analyzing the CAGR from 2016 to 2022. Even if the year 2023 is included in the CAGR, assuming that there will be no further research after June 30, the ratio is 8.45, which is an impressive result (Ekmen & Kocaman, 2023).

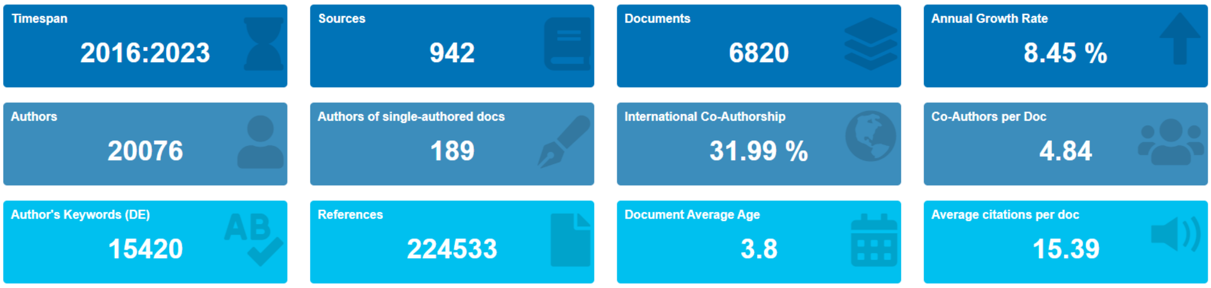

Figure 4.15. Overview of bibliometric data.

4.2.2. Yearly Analysis of Scientific Production

The bar graph (Figure 4.16) gives a chronological progression of published SDG 11-related RS articles from 2016 to 2022. It shows a clear upward trend in publication volume. Starting with 437 articles in 2016, there is a steady annual increase, rising to 467 in 2017. The growth becomes more significant in the following years, with 606 articles in 2018, jumping to 811 in 2019. The upward trend continues with 1022 articles in 2020, reaching 1200 in 2021. This increase peaked in 2022 when it reached 1506 articles.

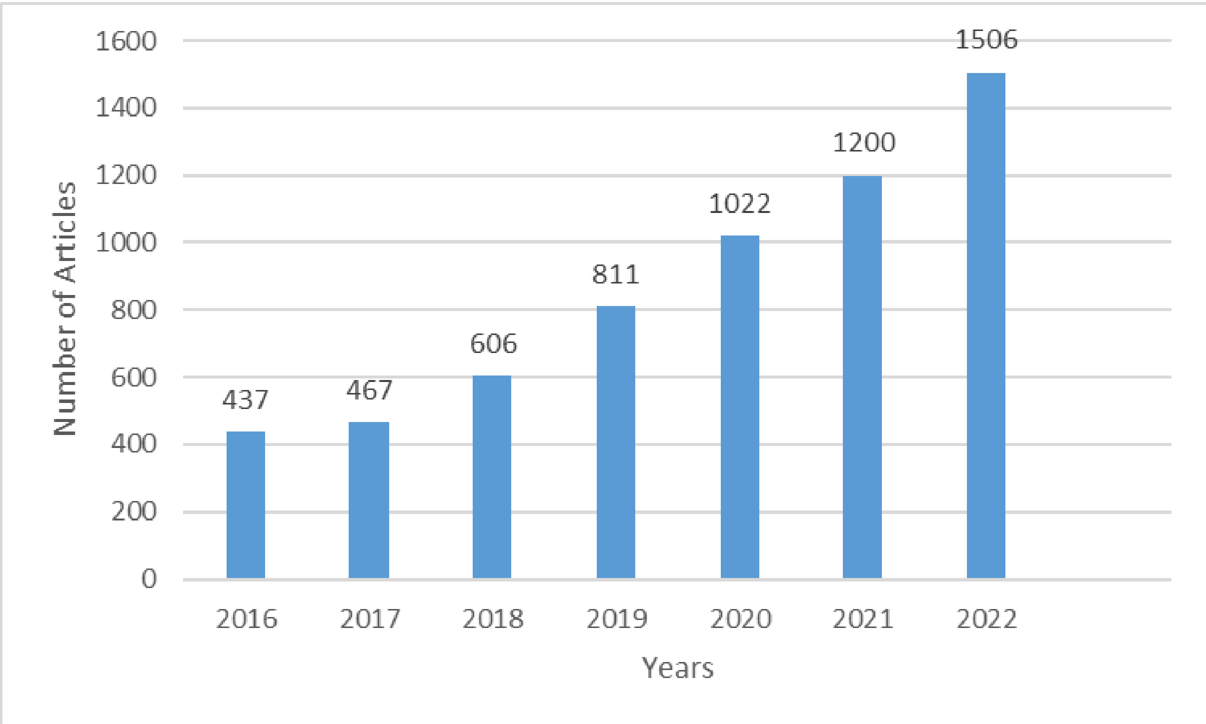

Figure 4.16. Scientific production by year (Ekmen & Kocaman, 2023).

4.2.3. Top Journals in the Realm of Remote Sensing Research Related to SDG 11

Of the top 20 journals on the subject (Table 4.5), *Remote Sensing* takes the lead with a substantial 860 articles, followed by *Sustainability* with 367. *Land* and *Science of the Total Environment* have published 178 and 137 articles respectively. *ISPRS International Journal of Geo-Information* contributed 134 articles. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* is not far behind with 129 articles. Of the remaining journals, *Ecological Indicators* has published 112 articles, *International Journal of Environmental Research and Public Health* 97, *Environmental Monitoring and Assessment* 93, and finally *International Journal of Applied Earth Observation and Geoinformation* has published 89 articles.

Table 4.5. Most relevant journals.

Journals	**N. Of Articles**
Remote Sensing	860
Sustainability	367
Land	178
Science of the Total Environment	137
ISPRS International Journal of Geo-Information	134
IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	129
Ecological Indicators	112
International Journal of Environmental Research and Public Health	97
Environmental Monitoring and Assessment	93

International Journal of Applied Earth Observation and Geoinformation	89
Journal of the Indian Society of Remote Sensing	79
Remote Sensing of Environment	79
ISPRS Journal of Photogrammetry and Remote Sensing	76
Egyptian Journal of Remote Sensing and Space Sciences	74
Sensors	74
Remote Sensing Applications-Society and Environment	70
Land Use Policy	66
Water	66
Atmosphere	65
Sustainable Cities and Society	64

According to Bradford's Law, within a collection of 942, 11 were identified as core sources, indicating that they fall into zone 1. This classification suggests that these selected journals are the most productive journals in the field. Core sources are the following respectively: *Remote Sensing, Sustainability, Land, Science of the Total Environment, ISPRS International Journal of Geo-Information, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, Ecological Indicators, International Journal of Environmental Research and Public Health, Environmental Monitoring and Assessment, International Journal of Applied Earth Observation and Geoinformation, Journal of the Indian Society of Remote Sensing* (Figure 4.17).

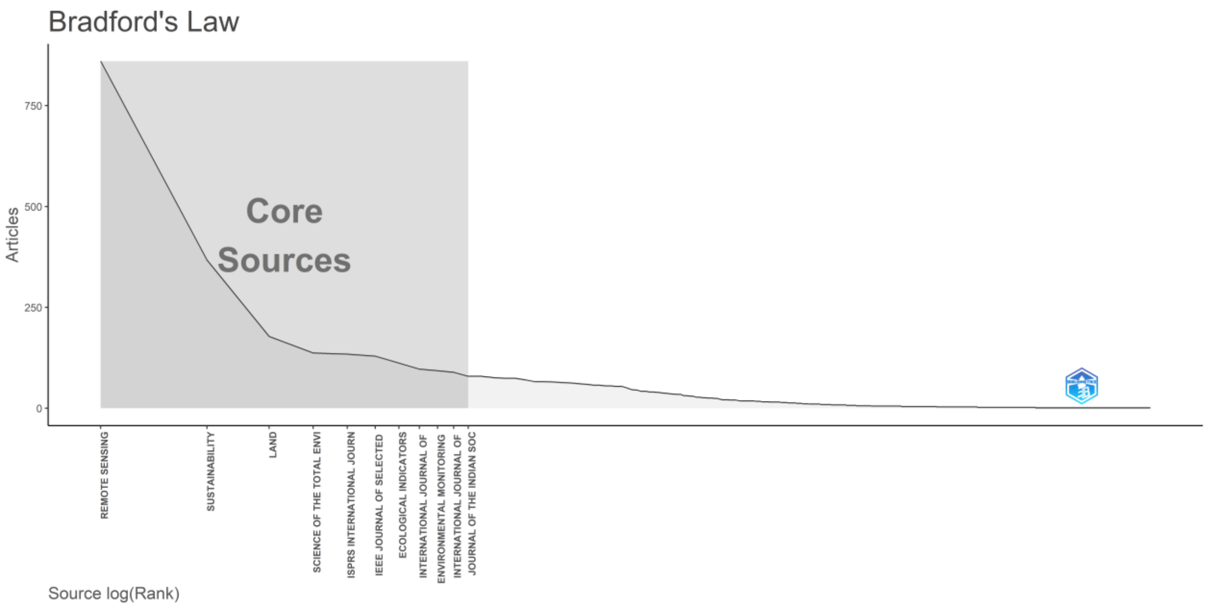

Figure 4.17. Bradford's Law.

4.2.4. Most Cited Articles in the Field of Remote Sensing Research in Relation to SDG 11

The 20 most cited articles on LC basis are listed in Table 4.6. The most locally cited research paper was written by Xisheng Hu and Hanqiu Xu in 2018, with 97 local citations. In this paper, an original RS-based ecological index (RSEI) was proposed to assess the ecological status of cities (Hu & Xu, 2018). The RSEI is one of the most frequently used indices for the extensive assessment of environmental quality, which is fully based on remote sensing data and can rapidly monitor environmental conditions over a large region (Wang et al., 2023).

Table 4.6. Most locally cited articles.

Articles	Year	LC	GC	LC/GC Ratio %
HU XS, 2018, ECOL INDIC	2018	97	220	44,09
HU TY, 2016, REMOTE SENS-BASEL	2016	87	257	33,85

XU HQ, 2018, ECOL INDIC	2018	83	173	47,98
PAL S, 2017, EGYPT J REMOTE SENS	2017	73	280	26,07
ZHU Z, 2019, REMOTE SENS ENVIRON	2019	61	166	36,75
TRAN DX, 2017, ISPRS J PHOTOGRAMM	2017	60	293	20,48
SINGH P, 2017, SUSTAIN CITIES SOC	2017	60	221	27,15
LIU XP, 2017, INT J GEOGR INF SCI	2017	59	194	30,41
YAO Y, 2017, INT J GEOGR INF SCI-a	2017	55	254	21,65
GONG P, 2019, SCI BULL	2019	51	244	20,90
SHAN W, 2019, J CLEAN PROD	2019	51	124	41,13
ESCH T, 2017, ISPRS J PHOTOGRAMM	2017	50	219	22,83
HUANG B, 2018, REMOTE SENS ENVIRON	2018	50	332	15,06
DU HY, 2016, SCI TOTAL ENVIRON	2016	49	230	21,30
HUANG X, 2019, ISPRS J PHOTOGRAMM	2019	48	216	22,22
YUE H, 2019, IEEE ACCESS	2019	47	80	58,75
CHEN LP, 2018, PLOS ONE	2018	46	183	25,14
AVDAN U, 2016, J SENSORS	2016	43	262	16,41
ZHANG XY, 2017, ISPRS J PHOTOGRAMM	2017	42	150	28,00
ESTOQUE RC, 2017, ISPRS J PHOTOGRAMM	2017	40	148	27,03

4.2.5. Analysis of Contributions by Affiliation and by Country in the Field of Remote Sensing Research in Relation to SDG 11

In the context of this work, the top 20 relevant affiliations, assessed by the number of articles, are shown in Table 4.7. These affiliations have demonstrated substantial productivity in SDG 11-related RS articles, contributing to the subject. Table 4.8 lists the countries of the top 25 corresponding authors. China leads with 2895 articles, of which 2179 are SCPs and 716 are MCPs. China is followed by the USA with 580 articles, of which 384 are SCPs and 196 are MCPs. India and Italy contribute 429 and 230 articles, respectively. India has 360 SCPs and 69 MCPs, while Italy has 153 SCPs and 77 MCPs. Particularly, Malaysia (MCP ratio of 0.625), the United Kingdom (MCP ratio of 0.598), and Australia (MCP ratio of 0.558) are noted for their high degree of international cooperation.

Table 4.7. Most relevant affiliations.

Affiliation	N. of Articles
WUHAN UNIV	402
UNIV CHINESE ACAD SCI	343
INST GEOG SCI AND NAT RESOURCES RES	233
CHINA UNIV GEOSCI	204
BEIJING NORMAL UNIV	172
AEROSP INFORMAT RES INST	168
CHINESE ACAD SCI	156
NANJING UNIV	141
PEKING UNIV	139

SUN YAT SEN UNIV	137
SHENZHEN UNIV	112
TSINGHUA UNIV	105
INST REMOTE SENSING AND DIGITAL EARTH	99
ARIZONA STATE UNIV	95
EAST CHINA NORMAL UNIV	94
HENAN UNIV	87
NANJING UNIV INFORMAT SCI AND TECHNOL	87
ZHEJIANG UNIV	82
HONG KONG POLYTECH UNIV	76
NANJING NORMAL UNIV	68

Table 4.8. Corresponding author's country.

Country	**Articles**	**SCP**	**MCP**	**MCP Ratio**
China	2895	2179	716	0,247
USA	580	384	196	0,338
India	429	360	69	0,161
Italy	230	153	77	0,335
Germany	222	125	97	0,437
Brazil	148	106	42	0,284
United Kingdom	132	53	79	0,598

Australia	113	50	63	0,558
Iran	107	67	40	0,374
Turkey	104	101	3	0,029
Egypt	101	51	50	0,495
Canada	95	61	34	0,358
Japan	91	49	42	0,462
Spain	81	55	26	0,321
Pakistan	68	44	24	0,353
South Africa	68	51	17	0,25
Saudi Arabia	66	30	36	0,545
France	63	29	34	0,54
Korea	61	35	26	0,426
Malaysia	56	21	35	0,625
Greece	54	27	27	0,5
Netherlands	51	25	26	0,51
Poland	48	32	16	0,333
Belgium	46	21	25	0,543
Indonesia	44	24	20	0,455

A map in Figure 4.18 shows the level of cooperation between countries. Two countries are connected by a red line, which indicates the level of cooperation between them. The level of cooperation is represented by the thickness of the red line. According to the map, the most collaboration is observed between China and the USA.

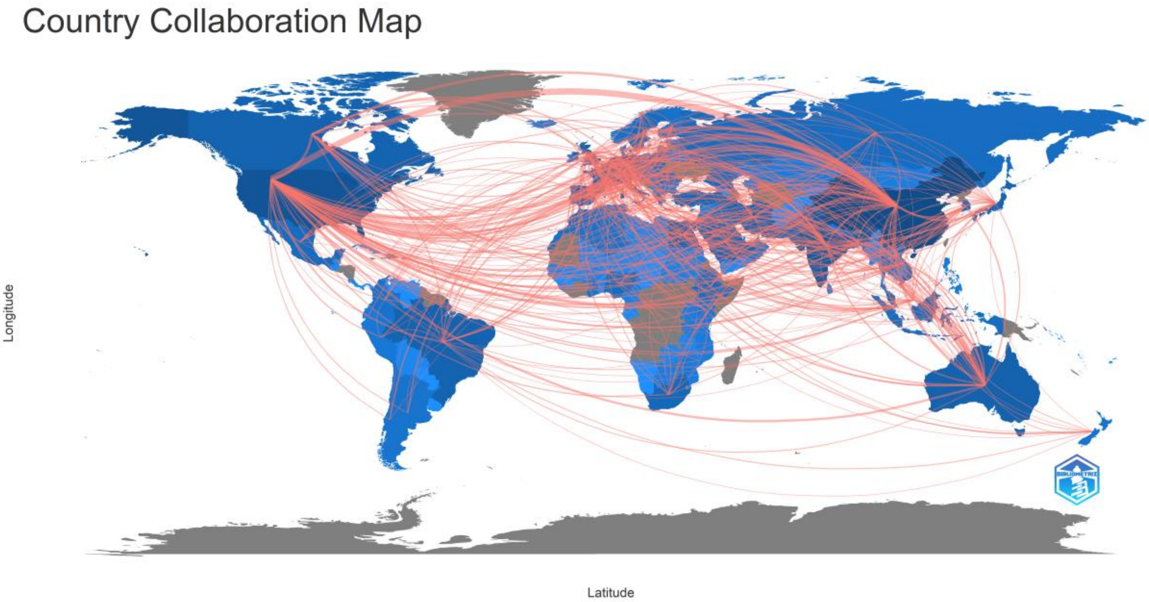

Figure 4.18. World map of collaboration.

4.2.6. Analysis of Keywords Used in Remote Sensing Research Related to SDG 11

Table 4.9 illustrates the cumulative growth of the top 20 author keywords in RS studies related to SDG 11 over the period from January 1, 2016 to June 30, 2023. A consistent upward trend can be seen for all of the keywords in the table.

Table 4.9. Cumulative growth of top 20 author keywords.

Keywords	**Years**							
	2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Remote Sensing	148	305	479	743	1085	1508	2011	2273
GIS	47	79	133	205	265	334	427	466
Urbanization	29	56	101	162	208	275	355	401

Land Use	18	26	50	87	130	184	246	281
Land Surface Temperature	17	36	57	87	140	185	253	277
Deep Learning	0	6	13	32	59	112	187	226
Urban Heat Island	16	33	46	79	119	156	200	220
Landsat	15	33	50	71	112	137	170	189
Machine Learning	2	4	11	24	57	94	139	171
Land Cover	6	13	33	47	75	96	141	159
China	11	18	32	62	91	112	137	148
Urban Expansion	8	18	31	53	75	96	134	145
Change Detection	9	19	32	51	70	91	122	143
Climate Change	5	11	23	38	59	79	118	139
NDVI	9	24	34	47	64	84	116	129
Urban Planning	8	16	22	38	50	78	106	118
Google Earth Engine	1	1	3	10	27	47	94	117
MODIS	16	22	31	43	58	79	98	107
Urban Sprawl	9	17	24	44	63	81	102	106

After identifying the top 25 Keywords Plus terms and adding the plural forms of these 25 terms to their singular forms, a word cloud (Figure 4.19) was generated from 22 Keywords Plus.

Figure 4.19. Word cloud from Keywords Plus.

As a continuation of the aforementioned keyword analysis, a further word cloud (Figure 4.20) was generated using the 25 most dominating bi-gram terms (N-gram: 2) from the abstracts of the articles.

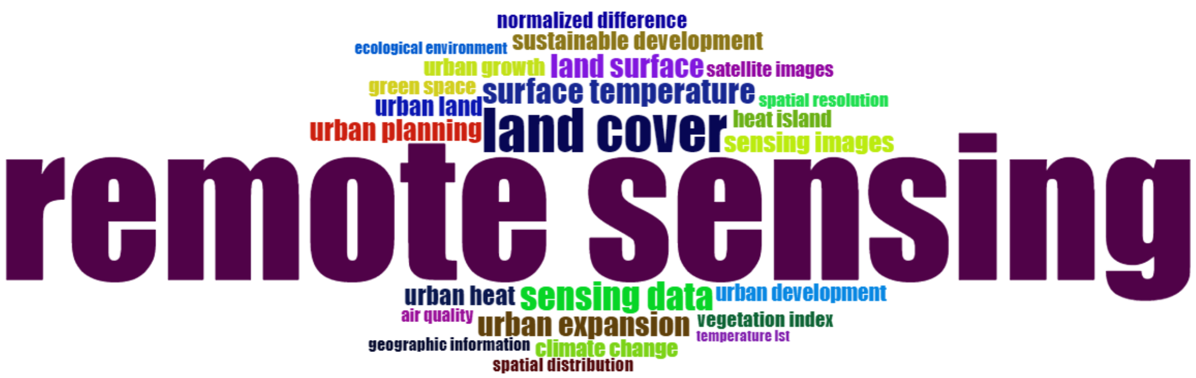

Figure 4.20. Word cloud from abstracts.

4.2.7. Conceptual Analysis

The thematic map in Figure 4.21 illustrates the results of the thematic analysis using author keywords, supported by the application of Callon's centrality and density indices. Callon's centrality reflects the intensity with which a given cluster relates to other clusters (Callon et al., 1991). In contrast, Callon's density is a measure of the strength of the connections among the words that form the cluster (Callon et al., 1991).

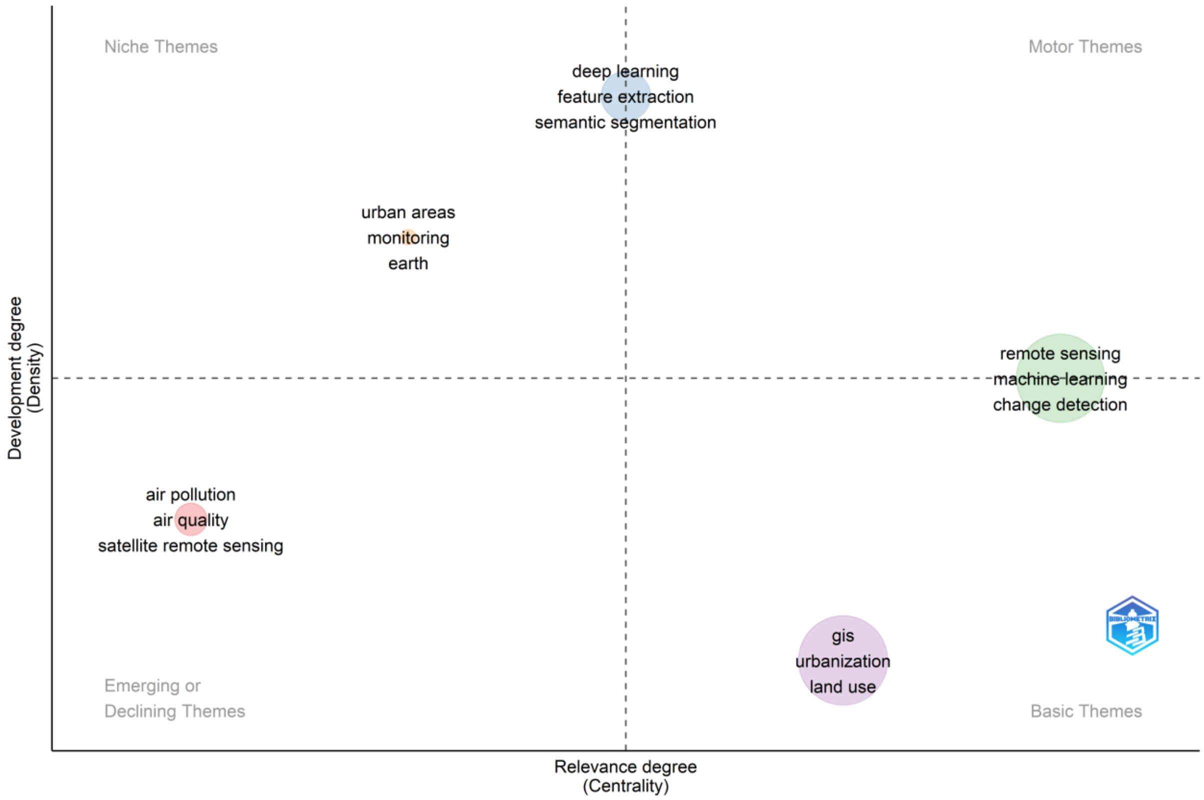

Figure 4.21. Thematic map (Ekmen & Kocaman, 2023).

5. DISCUSSION

The main motivation for this thesis was to underline the potential of RS/EO technologies to contribute to the SDGs in general, and to urban sustainability in particular. In addition, a comprehensive evaluation on SDG11 was carried out. This research has successfully achieved this goal by quantifying and assessing this potential.

In the first phase of this research, the relevance of RS technologies to all SDGs was explored. This synoptic perspective helped to understand the impact of RS technologies on sustainable development in general. This is because the RS technologies have the capacity to collect and analyze data in different areas, regardless of rural-urban, land-water, etc.

While exploring the relationship between RS and SDG 11 in depth, the number of articles was limited with appropriate keywords and filtering processes in the analysis with all SDGs. This decision was important to maintain the accuracy of the additional analyses (gender distribution and SDG classification) performed in the first phase of the thesis. As widely known, analyses that require manual work require strict controls to manage the risk of errors. In this thesis, it was a strategic choice to optimize the size of the dataset so that the manual operations could be performed with minimal errors. Therefore, the reliability of the results was increased by controlling the number of articles.

Considering both the evolution of SDG-related RS studies and SDG-11 related articles between 2016 and 2022, it was observed that the number of articles increased over the years. This increase is an indication that the research topic of this thesis is attracting more and more attention from researchers. This trend also reflects the growing recognition of the critical importance of RS in the field of SDGs. Such a trend proves that sustainable development, and urban sustainable development in particular, is a global challenge.

When the most relevant journals were analyzed within the scope of the research topics of this thesis, it is seen that the first two ranks remain unchanged. However, the distribution of journals also revealed the multidisciplinary nature of the research topics of this thesis. The authors with the most publications in SDG-related RS articles were Gregory Giuliani and Stefano Nativi (Ekmen & Kocaman, 2024). In this context, it is also possible to mention the joint articles of these authors (e.g. Giuliani et al., 2020; Nativi et al., 2019).

When the SDG-related RS papers were ranked by the LC, the 2017 study by Katherine Anderson and her colleagues was ranked first (Ekmen & Kocaman, 2024). This paper (Anderson et al., 2017) discussed the critical role of EO in supporting the achievement of the SDGs. In addition, it explored the contribution of the GEO to the effective use of EO in the context of the 2030 Agenda. The study by Michele Melchiorri and his colleagues in 2019 ranked second. This paper (Melchiorri et al., 2019) described the role of the Global Human Settlement Layer (GHSL) in providing detailed spatial information on human settlements. This work claims that SDG 11.3.1 can be moved from a Tier II classification to a Tier I classification with the aid of the GHSL.

On the other hand, when the RS research articles in relation to SDG 11 were ranked based on LC, Hu and Xu's 2018 study ranked first (Ekmen & Kocaman, 2023). The article (Hu & Xu, 2018) introduced a novel RSEI to evaluate urban ecological quality, focusing on Fuzhou City in China from 2000 to 2016. Hu et al.'s 2016 study came in second. Their study (Hu et al., 2016) presented a new method for generating high-resolution urban land use maps by combining satellite imagery (Landsat 8) and social data (Open Street Map), and tested this method for Beijing, China. The method showed high overall accuracy. As underlined in the Results section, the LC ranking and the RC ranking were not the same. However, these different rankings provide different perspectives on the impact of the articles and serve as indicators of their recognition in the domain of the articles directly covered by this thesis and in other domains.

In terms of authors' affiliations, there is evidence that Chinese institutions have been at the forefront. Regarding international cooperation, it can be said that the strongest scientific cooperation has been observed between China and the USA. When the countries were analyzed through corresponding authors, the top four countries in SDG-related RS studies are China, the USA, Italy and the United Kingdom (Ekmen & Kocaman, 2024), while the top four countries in SDG 11-related RS studies were the USA, China, India and Italy (Ekmen & Kocaman, 2023). The MCPs calculated in the same analysis reveal the extent of international cooperation in RS research on the SDGs in general and SDG 11 in particular, which are the exploratory topics of this thesis. Across all fields of science and technology, international cooperation is on the rise (Wagner, 2006). This thesis confirms this claim from the perspective of RS and SDG relations.

In this thesis, the co-citation networks of articles and journals related to SDG-related RS studies have been extracted. By mapping these co-citation networks, the aim is to contribute to the understanding of the landscape of SDG-related RS research. The structure of a field can be revealed by co-citation patterns (Chen, 1999).

In analyzing the trending topics, it is noticeable that carbon storage and ecological quality along with impervious surface have received more attention from researchers recently (Ekmen & Kocaman, 2024). Indeed, RS is increasingly becoming essential to accurately estimate and monitor the diversity, size and variability of carbon stocks in different ecosystems for effective reporting and verification (Campbell et al., 2022). Ecological quality assessment is another area where RS can be used in a practical way. For example, by using the cloud-based Google Earth Engine (GEE) platform and employing RSEI, it is possible to assess the quality of the ecological environment (Yang et al., 2022).

The keyword analysis also provided important insights. Regarding the SDG-related RS studies, the prominence of Landsat in the top 5 author keywords is significant (Ekmen & Kocaman, 2024), and most likely due to its longest archive and free availability. After Landsat, Sentinel-2 was the most common satellite among author keywords. The Sentinel-2 mission, part of the ESA's Sentinel satellite fleet, utilizes multispectral imaging technology. Its primary goal is to provide detailed imagery for tracking land use and land cover, monitoring climate change, and monitoring natural disasters, while also enhancing data collected by other satellites such as Landsat (Phiri et al., 2020). On the other hand, in the keyword co-occurrence analysis, 4 main groups were identified (Ekmen &

Kocaman, 2024): The blue cluster emphasized the use of RS to achieve the SDGs in a broad scope. There is a particular focus on the integration of free optical satellite data products, such as Landsat and Sentinel-2 in this cluster. Here, China stood out as a country. The red cluster highlighted the use of GEE for land cover and land use analysis. The green cluster linked the EO to sustainable development, linking it to the use of big Earth data and focusing on land degradation as a key application area. The violet cluster highlighted the relationship between essential variables (EVs) and SDG indicators. It is important to note that a single EV can feed multiple SDG indicators, as discussed by Reyers et al. (2017).

Analyzing the keywords in SDG 11-related RS studies also provided interesting insights. For example, the fact that deep learning and machine learning keywords find their place in the top 10 author keywords (Ekmen & Kocaman, 2023) also indicates a paradigm shift in the RS field. This transition is directly related to the transition from traditional parametric classifiers to machine learning classifiers. Nevertheless, in spite of the growing acceptance of machine learning classifiers, parametric methods are still widely available in application papers and remain one of the main standards for comparing classification experiments (Maxwell et al., 2018). The Keywords Plus analysis revealed that topics such as regional development, disaster resilience, natural and cultural heritage, and inclusiveness were underrepresented compared to frequently used words (Ekmen & Kocaman, 2023).

The thematic map using author keywords for SDG 11-related RS studies looked like a coordinate system (Figure 5.1). In this coordinate system, clusters falling in the upper right part are motor themes, those falling in the upper left part are niche themes, those falling in the lower left part are emerging or declining themes, and those falling in the lower right part are basic themes.

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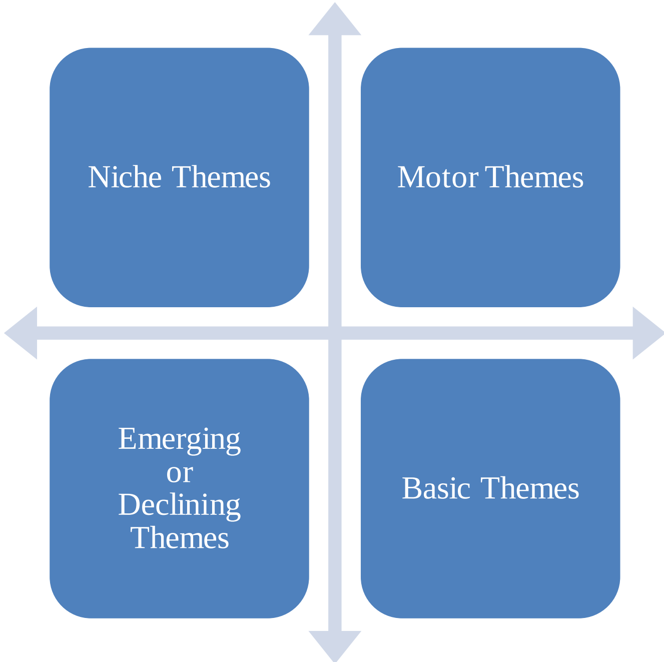

Figure 5.1. Zones on the thematic map.

While the 3 of the 5 clusters identified as a result of the conceptual analysis remain within a single region in the coordinate system, the remote sensing cluster had both basic themes and motor themes features, and the deep learning cluster had both motor themes and niche themes features (Ekmen & Kocaman, 2023). The coexistence of basic and motor themes features in the remote sensing cluster suggested that this cluster was both foundational and dynamic. Likewise, the deep learning cluster had a dual nature. The coexistence of motor and niche themes features in this cluster indicated not only a highly specialized area of research, but also rapid development and innovation.

As an additional analysis, the SDG-related articles were classified according to each goal. Two striking results emerged from this analysis: First, articles were classified as most relevant to SDG 15 and SDG 11 (Ekmen & Kocaman, 2024). However, many SDG 15-related articles were also related to SDG 11. Secondly, SDG 11, which is also analyzed in detail in this thesis, was the SDG that was most often discussed alone.

The gender distribution analysis (Figures 4.12 and 4.13) indicated the dominance of males as first and corresponding authors in the field. Additionally, due to unconfirmed professional profiles and/or gender-neutral first names, around 4% of first authors and 3% of corresponding authors had unknown sex. Since a significant part of the processing was performed manually, there may also be operator errors. This investigation assumed that each article had only one first author, and co-first authorship was not taken into account. Although there was an increasing trend in male/female ratio of first authors between the years 2017 and 2019, and reached to 55/45 in 2019; it dropped down to 70/30 between the years 2020 and 2022. The underrepresentation of female first authors and corresponding authors in the articles analyzed may be due to a number of systematic and social reasons. For example, the juggling act between family responsibilities and pursing an academic career can be particularly challenging for women. Maintaining work-family balance may become even more difficult, especially during crisis periods such as the recent COVID-19 pandemic. UN Women (2022) also emphasized that the gender equality actually started to decline globally due to COVID-19, the climate emergency, and the growing economic and political uncertainty. The decline in the percentage of female corresponding authors was not improved and remained as 25% in 2022. The lack of female role models who can be an inspiration to other women in science may be another reason. In addition, career choices are often made at an early age. At this stage, traditional gender roles may influence career choices. This may explain the low proportion of women who are first or corresponding authors in this domain.

It is also helpful to mention the limitations of this thesis in order to clarify its credibility and scope, and to help the reader understand the conditions under which the analysis is valid. In this study, papers written in English and with the category of research article only and exclusively have been selected. However, it should be noted that there are many useful studies in other languages. The WoS Core Collection database was used in this study. It is important to note that useful studies could also be found in other databases such as Scopus.

6. CONCLUSIONS AND THE WAY FORWARD

This chapter has two subheadings. The first subheading contains conclusions. The second subheading is a projection for future studies.

6.1. Conclusions

This thesis undertook a comprehensive analysis of the intersection between the SDGs and RS studies. It used the Bibliometrix R package to explore different dimensions of this critical area. In addition to assessing thematic trends and emerging themes etc. in SDG-related RS research, the study also examined gender distribution and international collaboration in the field.

In this study, first the overlapping field of SDGs and RS was analyzed in many aspects, then the gender distribution of first authors and corresponding authors of these studies was analyzed, and finally they were classified based on SDGs. Then, the study was specificized and a large corpus of SDG 11-related RS studies was analyzed using the Bibliometrix R package. In this way, it has been possible to produce a thesis that can serve as a guide for policy makers, scholars in the field, and researchers who intend to enter in this domain.

The analyses in this thesis revealed an ascending trend in both SDG-related RS studies and urban-related RS studies. This trend was an indication that it would continue in the years to come. As it is already known, with the end of 2023, more than half of the time covered by the 2030 Agenda has already passed, so it is important to accelerate the work in this topic in order to realize the targets underlying the SDGs.

Within the framework of the subject of this thesis, it was also important to identify trend topics in order to show where studies could develop. In addition to carbon storage (relevant to SDG 13) and ecological quality (relevant to SDG 15 and SDG 14) trending in SDG-related RS research, impervious surface, a key component of urban areas, is particularly meaningful for SDG 11. When SDG 11-related RS research was analyzed conceptually, it was found that machine learning and change detection had a dual nature with both basic and motor themes; while deep learning, feature extraction, and semantic segmentation had a dual nature with both motor and niche themes.

The common point that all of the keyword analyses within the scope of this thesis pointed out is that this research topic is very suitable for interdisciplinary studies. The distribution of most relevant journals also implies the same point. From this point of view, it is clear that a holistic approach (an encompassing perspective) to this research topic is useful and even essential.

By finding the MCPs of the countries, this thesis has demonstrated the magnitude of international cooperation in the science of sustainable development and especially urban sustainable development. It has also indirectly shown that SDGs are a matter of global concern. It can also be seen as a reflection of the target audience (whether the whole world or developing countries), which is an issue that distinguishes the SDGs from the MDGs.

In the analysis of gender distribution, it is noteworthy that the proportion of female corresponding authors was lower than the proportion of female first authors. Corresponding authorship involves a kind of leadership role, as Wang et al. (2013) point out in their study. From this perspective, it can be said that men find proportionally more roles in academic leadership. This thesis reported that male dominance continues in the field. As also stated by Tran et al. (2022), methods such as double-blind peer review to mitigate gender bias can help minimize gender inequalities in academic production.

It is also helpful to mention the limitations of this thesis in order to clarify its credibility and scope, and to help the reader understand the conditions under which the analysis is valid. In this study, papers written in English and with the category of research article only and exclusively have been selected. However, it should be noted that there are many useful studies in other languages. The WoS Core Collection database was used in this study. It is important to note that useful studies could also be found in other databases such as Scopus.

In conclusion, this work contributes valuable insights to the field of SDG-focused RS / EO research and serves as a roadmap for policymakers, academics, and researchers. Going forward, concerted efforts are needed to leverage disruptive technologies and interdisciplinary approaches to accelerate progress towards the SDGs and promote inclusive and sustainable development on a global scale.

6.2. Future Work

Future work should aim to maximize the potential of remote sensing technologies to contribute to sustainable development and sustainable urban development. For example, future studies that provide innovative ideas for processing and analyzing remotely sensed data will strengthen the role of remote sensing in achieving the SDGs.

The AI tools, which are becoming more important every day, should be used more intensively to achieve the SDGs. At this point, the two approaches should be utilized together. First, the AI can play a role in achieving 134 targets, as presented by Vinuesa et al. in their 2020 study. Whether this number can be further increased needs to be explored. Second, more thought should be given to how to develop further SDG-related applications where AI is already being used. For example, it is beneficial to increase the number and capacity of AI tools, such as the OSDG tool used in this thesis.

When developing RS-based solutions for sustainable development, it is important to consider more than just satellite remote sensing, which is often the first aspect that comes to mind. By integrating data from different remote sensing platforms (satellite, drone, etc.), it may be possible to go further in achieving the SDGs. For example, in the case of SDG 11, more comprehensive models of cities can be built in this way.

Data from social media and crowdsourcing platforms can be combined with remote sensing technologies to provide in-depth insights into sustainable cities and the needs of their residents. These efforts can make the path to sustainability more participatory.

SDG 11-related RS studies were investigated in detail. A similar study can be carried out for SDG 15. This is because, as this thesis study showed, SDG 15 and SDG 11 have been the most common topics in the SDG-related RS studies.

The other limitations of this study were language and the exclusion of various academic databases from the scope of the study. However, it is clear that there may be remarkable studies in languages other than English and in databases such as Scopus. Therefore, enhancements regarding these limitations can be considered in future work.

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