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RESEARCH TRENDS IN WATER MANAGEMENT IN CENTRAL AND EASTERN EUROPE IN THE CONTEXT OF CIRCULAR ECONOMY

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Abstract

Water resources are highly valuable globally, and their sustainable management has become a top priority for authorities worldwide. Central and Eastern European (CEE) countries, with their extensive history of water usage across various sectors, face significant challenges due to the over-exploitation of these resources. The increasing demand underscores the need for comprehensive management at both national and regional levels. This study examines research trends on water resource exploitation in CEE countries, identifying potential research gaps that academia can address to offer essential a valuable insight for policymakers. By using a bibliometric analysis of 390 articles and proceedings from the Web of Science database, analysed through VosViewer software, the study reveals substantial research interest in areas such as agriculture, water management, wastewater reuse solutions, and sustainable agricultural water use. Despite this, the analysis indicates a notable deficiency in research focused on the new labour market demands associated with emerging water management technologies. These findings highlight the necessity for future research to bridge this gap, providing actionable insights to adapt educational and training programs to the evolving requirements of the water management sector.

Key words*: bibliometric analysis, circular economy, circular water, water sustainable, water use, wastewater reuse.*

INTRODUCTION

Water is one of the most important resources that allowed urban development, being linked to the agriculture sector, food industry, hospitality, construction or transportation. According to the United Nations, the humanity is facing a water crisis that impacts the economy in many ways, all the countries being affected, no matter their developing degree. For example, in developing states the main issues are related to the water quality and in the developed countries the main concerns are related to the availability of water for irrigation (UNESCO, 2024).

The most water-consuming activity is agriculture, being responsible on 70% of the total water use worldwide (OECD, 2024). In the context of the growing demand for food, there is an unprecedented pressure in this sector, especially in the months when irrigation water can be available only using unsustainable methods (Rosa et al., 2020). According to FAO projections, by 2050 the demand for food will increase by 50% (FAO, 2023) which will maximize the needed quantity of water in agriculture.

The transition towards a circular economy has gained significant momentum in recent years, with environmental legislation and policy plans increasingly incorporating the circular economy concept into business development. This paradigm shift is particularly crucial in the water management sector, where sustainable practices are essential for resource recovery and environmental preservation (Sandu et al., 2023). In Central and Eastern Europe, researchers have been exploring various approaches to enhance the circularity of water management systems. One such approach is the implementation of anaerobic membrane bioreactors (AnMBRs), which have been identified as a promising technology for simultaneous recovery of clean water, renewable energy, and nutrients from municipal wastewater (Robles et al., 2021). Additionally, the concept of sewer mining, which involves extracting wastewater from local sewers for decentralized reuse applications, has garnered significant interest in the region as a means of bridging the gap between household-scale reuse and centralized treatment (Liakopoulou et al., 2020; Mannina et al., 2021).

Wastewater treatment plants (WWTPs) are also undergoing a critical transition, shifting from a linear to a circular economy operation and design concept. This transition involves the recovery of resources, such as water, energy, and materials, from the wastewater stream, with the ultimate goal of minimizing waste and preserving natural resources. Researchers in Central and Eastern Europe have been exploring various strategies to enhance the circularity of wastewater treatment, including the recovery of nutrients, the valorisation of sewage sludge, and the generation of renewable energy from the wastewater stream (Guerra-Rodríguez et al., 2020).

Depending on the location and the weather hazards that take place in a period, there are locations where water may not be available at all for short periods. This is common to the developing countries, arctic regions or isolated rural places. Even though in the last decades the tools for conserving water have developed constantly, in these regions is still common for the citizens to use tankers for preserving water which may represent a health risk for the local population (Salehi, 2022). Water recovery is not so easily to achieve by the citizens, as they do not have the needed infrastructure to recover water and reuse it in household activities. The integration of wastewater in different activities is still limited by the health and environment constraints (Berbel et al., 2023).

Besides the technological issues in recovery wastewater, there are other aspects that should be considered when it comes to a sustainable water management. In tourism, for example, the simplest solution is to increase the awareness among the guests. But messages that make clients more aware about the importance of their behaviour, like saving water when soaping, have limited effects as the tourist's behaviour depends on their culture and their awareness regarding this topic is low (Borys et al., 2023). On the other hand, the hotels can choose to use products that are 99% biodegradable and have a reduced impact on aquatic life (Koseoglu-Imer et al., 2023) or use intelligent devices to doze the water quantity. However, these kinds of initiative are not enough to accomplish a scalable result and higher investments are required which highlights the issues related to the costs that are still too big for the small business. The change in consumer behaviour is difficult to achieve in the household sector also. As the water demand does not depend on the price in the household sector (European Environment Agency, 2021), it is difficult to constraint the citizen to save water. This puts more pressure on the authorities to find solutions to educate citizens in this regard.

In this context, and in line with the European Green Deal program, water management became one of the European Commission priorities, being an essential part of the transition to the circular economy model (Smol et al., 2020; Sandu & Vîrsta, 2021) from the linear one, that in this filed involves the disposal of process materials in activities like desalinations and wastewater treatment (Yusuf et al., 2020). In order to assure the circularity in water management, the stakeholders should meet the following five rules: circularity, multiple waters, involving digital tools, using inclusive water and resilient water (infrastructure) (Water Europe, 2024). All these concepts have the role to assure both quality and availability of water resources in Europe. Digital water, for example is a smart way to control water resources involving AI tools to optimize environmental planning and management policies (Nikolaou et al., 2020). The switch to a circular approach in water use is beneficial for the labour field also. In Europe, the implementation of innovative tools and processes for recovering water might provide up to 20000 new jobs (Koseoglu-Imer, 2023).

Starting with 2010, the Water Framework Directive establishes the rules that makes the member states to be more aware about the importance of the quality of water resources and the necessity to implement up-to-date water management solutions (European Commission, 2023). The legal framework was completed in 2023 by the Water Reuse Regulation (European Commission, 2023). This change is a consequence of the need of water in many economic fields, especially agriculture (Zahoor & Mushtaq, 2023), that are highly polluting and that affects both the quality of water and the disposable quantity.

In Europe, many countries are facing issues in water availability, mainly during the summer, when important quantities are used for irrigation. Many studies indicate the urge need for more action from the stakeholder in order to

prevent water pollution and water waste. In South-West Europe, where almost 13,5% of the territory uses water for irrigation and where are located ones of the major EU cities, water management became a necessity (Larraz, 2024). This region is also affected by the increased temperature. The climate-change scenarios indicate that in the next years water availability will continue to be a problem for agriculture (Sordo-Ward et al., 2019). The most affected member states are in the south-western region (Martínez-Valderrama et al., 2023). Even though other European countries seem to not face issues in terms of water availability, like Poland, there is always a risk in terms of quality and temporary interruption. So, innovative solutions should be found, like new shower panels that limit the quantity of water (Czajkowski et al., 2021), renewable water technology (Zhang et al., 2023), behavior-change interventions designed for the citizens (Halabieh & Shu, 2024) or implementing smart water monitoring systems (Alexopoulos et al., 2022).

Water governance is mandatory in the context of the climate change issues, the progress in agriculture and the requirements of the circular economy. So, more action to improve the behaviour of the stakeholders in terms of sustainable use of water resources is needed (Jägermeyr, 2020). In this regard, the first step is to identity the relevant research trends and gaps in research in order to give the decision makers a complex overview in the field. Analysing the most relevant sources in the literature, it can be seen there is many research that focus on the water conservation in specific areas like Mediterranean region (Garcia-Tejero, 2020), (Sismani et al., 2023) and on countries from CEE region, like Romania (Iojă et al., 2021; Timofti & Pienaru, 2022), Hungary (Gaál & Becsákné Tornay, 2023), Bulgaria (Negm et al, 2020), Poland (Kubiak-Wójcicka, 2021), Czech Republic (Zimková et al., 2023).

The present study completes the literature with a descriptive image about the research trends in water management in the CEE countries, with a focus on the region and less on the individual member states. The novelty of the present research is the geographical approach of the analysis and the aim to investigate if the labour market is considered a mature research topic in the context of the changes brought by the circular economy requirements. The main objectives of the paper are: **i)** to describe the scientific production of the papers that focused on the way the water resources are used in CEE region and **ii)** to identify the main research trends in the field.

Despite these challenges, numerous European countries are making significant steps forward in water management. For instance, Germany, with its advanced technological infrastructure, has implemented innovative water reuse and conservation strategies. Similarly, Poland has focused on improving water quality and expanding access to clean water in rural areas. China, while not in Europe, serves as a relevant case study due to its large-scale water management projects, such as the South-to-North Water Diversion Project, which aims to address water scarcity in its northern regions. Spain and the USA, with their diverse climates and water-intensive agricultural sectors, offer valuable insights into water management practices in different contexts. These examples highlight the importance of tailored solutions and collaborative efforts in addressing the multifaceted water crisis.

In regions of the world affected by water scarcity, economic activities can be constrained by water availability, leading to competition both among sectors and between human uses and environmental needs. While the commodification of water remains a contentious political issue, the valuation of this natural resource is sometimes viewed as a strategy to avoid water waste. Likewise, water markets have been invoked as a mechanism to allocate water to economically most efficient uses. However, the value of water remains difficult to estimate because water markets and market prices exist only in few regions of the world. Despite numerous attempts at estimating the value of water in the absence of markets, a global spatially explicit assessment of the value of water in agriculture is still missing. This lack of comprehensive data on the economic value of water in agriculture presents a significant challenge in transitioning towards a circular water economy, as it hinders effective decision-making and resource allocation (D'Odorico et al., 2020).

MATERIALS AND METHODS

In order to achieve a comprehensive image about the use of water resource in CEE countries, a bibliometric analysis was performed. The research was based on the simplified PRISMA protocol that is used in systematic review to describe the research stages in a transparent way (Page et al., 2021). The systematic review of the literature is one of the research methods that have a high contribution to knowledge in a field (Rowe et al., 2023), being used to describe bibliometric indicators and research trends in many domains, like agriculture (Pradhan et al., 2023), tourism (Huang et al., 2023), engineering (Nwaogu et al., 2023), education science (Oliveira & Bonito, 2023) and others.

The data was extracted from Web of Science database, one of the most relevant bibliometric databases worldwide that contains documents since 1900 (Web of Science, 2024) and which in countries like Romania is considered the baseline in academic publishing evaluation. The results were interpreted using VosViewer software, a validated tool used for bibliometric mapping (van Eck et al., 2010). In order to unify different variations of the same items, a Thesaurus file was built and used.

The research design is presented in Figure 1 and the data was filtrated to include in the topic (title, abstract and key words) the following items:

- water and
- resource*/management/consume/ supply and
- CEE/Central and Eastern Europe/ Central and Eastern Countries/ Central Europe/Eastern Europe.

The interrogation focused on CEE as a region, so the name of the countries from this area were not included in the search phase.

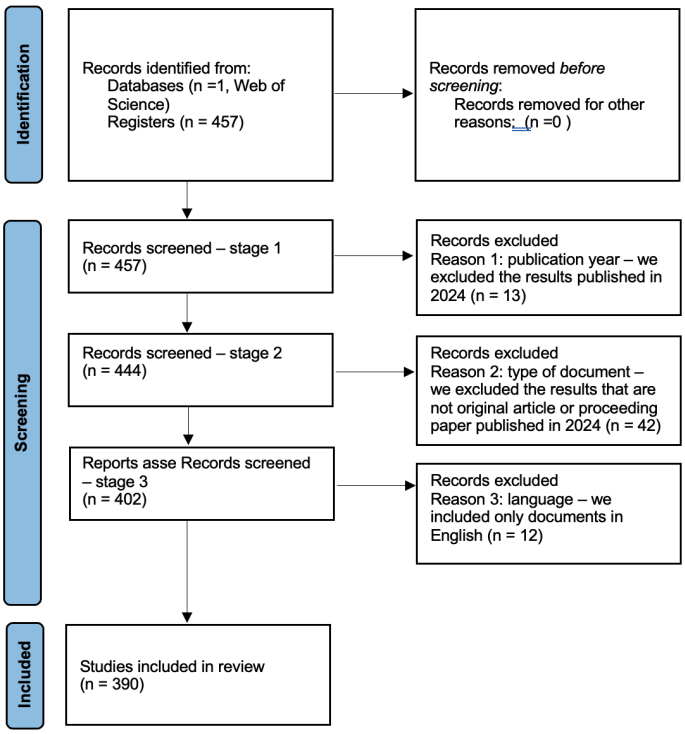

Figure 1. The research stages based on PRISMA protocol
(Source: Author elaboration based on Page et al., 2021)

The research included only original articles and proceedings papers written in English, as the novelty in research is the highest in these two types of documents. There were excluded

review articles as they are not considered relevant for the present investigation. There were included the documents published up to 2024. As the research was performed during 2024 and one of the objectives of the study is to describe the scientific production, analysing only a half of a year would not be relevant.

To enhance the validity and reliability of the findings, the research also incorporated a qualitative analysis of selected articles and proceedings papers. This analysis aimed to identify emerging themes, trends, and research gaps that may not be fully captured by bibliometric indicators alone. The qualitative analysis involved a close reading of the selected documents, with a focus on their research questions, methodologies, findings, and implications. The qualitative findings were then triangulated with the bibliometric results to provide a more comprehensive and nuanced understanding of the conducted research.

RESULTS AND DISCUSSIONS

The scientific production of the studies related to the water use in CEE region started to increase after 2010, the same year when the EU framework related to water management changed (Figure 2). The increase in published articles and proceedings is not exponential from one year to another, except 2020, the year when Green Deal Program started to be populated, and the trend is marked by ups and downs. This shows that the subject is of interest for the academic community and even though there is a change in the legislation framework in the member states, and the EU makes efforts to improve the circularity in this field, the topic was not artificially pushed by the EU Directives. Moreover, 56% of the total papers included in the study received funding for research, showing the high interest for the topic at national and international level from both funding bodies and research teams to access grants.

Overall, the research trends in water management in Central and Eastern Europe in the context of circular economy suggest a growing interest and commitment to addressing the complex challenges in this domain, though significant work remains to be done to achieve a truly circular water economy in the region (Díaz-García et al., 2020; OECD, 2022; Implementing Water Economics in the EU Water Framework Directive, 2023; Trică et al., 2019).

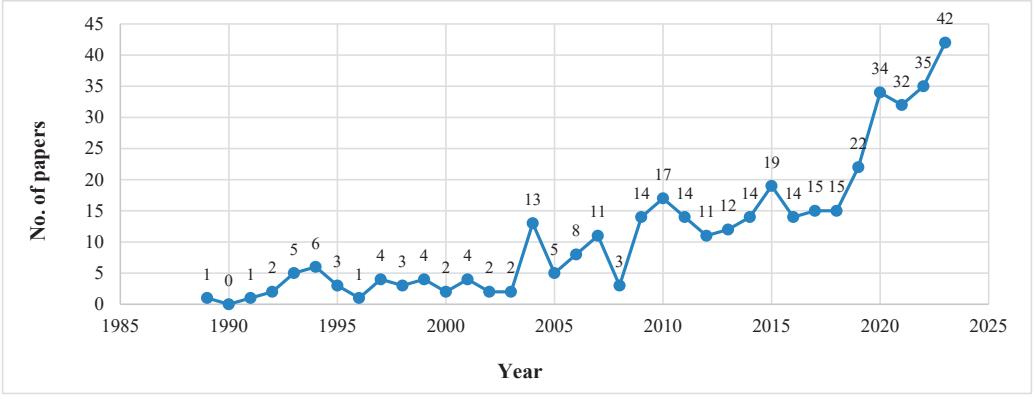

Figure 2. Scientific production

The countries that focus the most on this research topic are Germany (86 documents), Poland (43 document), China (40 documents), Spain (37 documents) and the USA (33 documents). Even though the investigated subject is related to the situation from the CEE region, except Poland, the other states from the CEE recorded a low scientific production in terms of studying the use of water resources in the region (Figure 3). Czech Republic had 26 documents, Hungary recorded 22 documents, Slovakia 12 documents, Romania 8 documents and Slovenia 7 documents. The highest impact of the published papers recorded Germany

(4611 citations), USA (3916 citations), England (3062 citations), Switzerland (2744 citations) and Netherlands (2700 citations).

The research interest in water management in CEE countries has been growing steadily, as evidenced by the increasing number of publications over time. This trend can be attributed to several factors, including:

- **Heightened awareness of water scarcity and climate change:** the escalating impacts of climate change, such as droughts, floods, and extreme weather events, have underscored the vulnerability of water resources in the region. This has prompted researchers and policymakers to prioritize water management research and develop adaptive strategies.
- **Policy and regulatory frameworks:** the implementation of the EU Water Framework Directive and the Water Reuse Regulation has created a regulatory environment that encourages research and innovation in water management. These frameworks have set ambitious targets for water quality and reuse, stimulating research activities aimed at achieving these goals.
- **Technological advancements:** the development of new technologies, such as smart sensors, remote sensing, and data analytics, has opened up new avenues for water management research. These technologies enable more accurate monitoring of water resources, better forecasting of water availability, and more efficient management of water use.

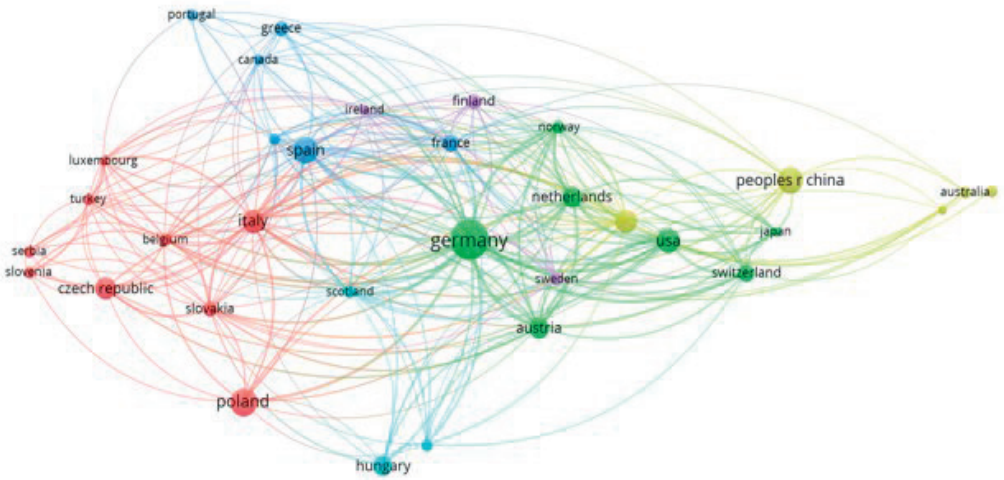

Figure 3. The affiliation map of the documents based on country
(* minimum number of documents of a country = 5)

Related to the interest for studding the sustainable ways to use water resources in CEE region, it can be observed (Figure 4) that the institutions that recorded the most articles and proceedings that met the present selection criteria are Chinese Acad Sci with 10 documents, University Kassel with 9 documents, Polish Academy of Science with 8 documents and University Utrecht and University Freiburg with 7 documents each. The impact of the published papers changes the rank of the research institutions. University Kassel recorded the highest number of total citations of the published papers (1704) followed by Potsdam Inst Climate impact res (1543 citations) and Chinese Acad Sci (11172 citations).

In order to eliminate plural forms of the resulted items and similar format of the key words (ex: climate change and climate-change), a Thesaurus file was used. After the unification step of the terms, resulted 110 key words that grouped the research interest regarding the sustainable use of water resources in CEE countries into six clusters (Figure 5).

The highly used items are climate change (occurrence = 70), management (42), impact (37), model (36) and drought (27).
The red cluster contains 28 items that are related to water management. The most relevant items, that are used in the most papers are: river basin management (occurrence = 20), management (42), pollution (12), quality (26), water framework directive (14), water quality (12).
The green cluster contains 27 items that are connected to climate change issues. The most common key words in the investigated papers are climate change (occurrence = 70), groundwater (18), precipitation (12), variability (18), water resource management (26).
The blue cluster consists of 20 items related to the consequences of climate change. The key words with the highest occurrence are climate (20), drought (27), emissions (19), irrigation (13).
The yellow cluster contains 18 items that are related to agriculture field. The most common key words are agriculture (occurrence = 14), impact (37), water management (12), temperature (12).
The purple cluster has 13 items connected to the water governance. The most common key words are system (18), consumption (8), ecosystem services (7), framework (8), water footprint (9), water scarcity (9).
The light blue cluster contains only 2 terms: adaptation (occurrence = 9) and projection (7), both of them having links with all the other clusters.

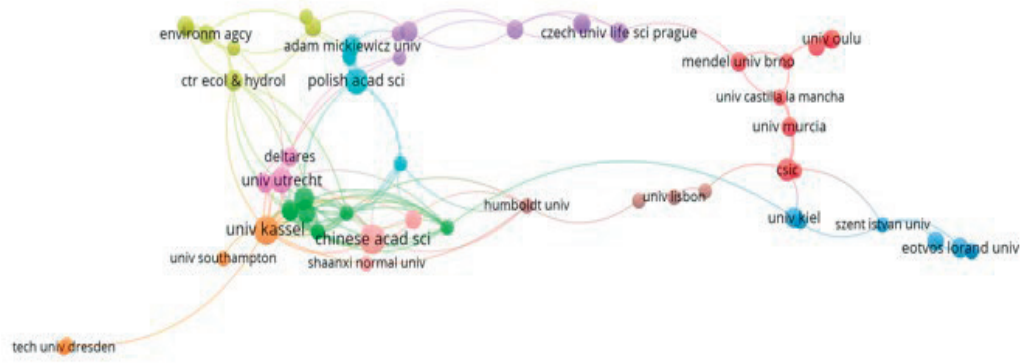

Figure 4. The affiliation map based on institution
(* minimum number of documents of a country = 3)

The analysis shows the research interest related to labour issues is low in this field and no cluster indicated directly the concerns related to the new requirements of the circular water in terms of job creation.
The terms that are indirectly connected to the labour market are framework, governance, adaptation, water framework directive, water governance, water management, water use efficiency.
The most research is focused on issues related to the climate change impact on the agriculture and the lack of water for irrigation, on sustainable ways to recover waste water and ecosystem services.
The analysis of the countries and institutions involved in this research reveals a diverse landscape with both regional and international collaborations. While Germany, Poland, China, Spain and the USA are leading contributors to the research output, there is a clear need for increased research capacity and collaboration within the CEE region itself. This is essential to ensure that research findings are relevant to the specific challenges and opportunities faced by these countries.

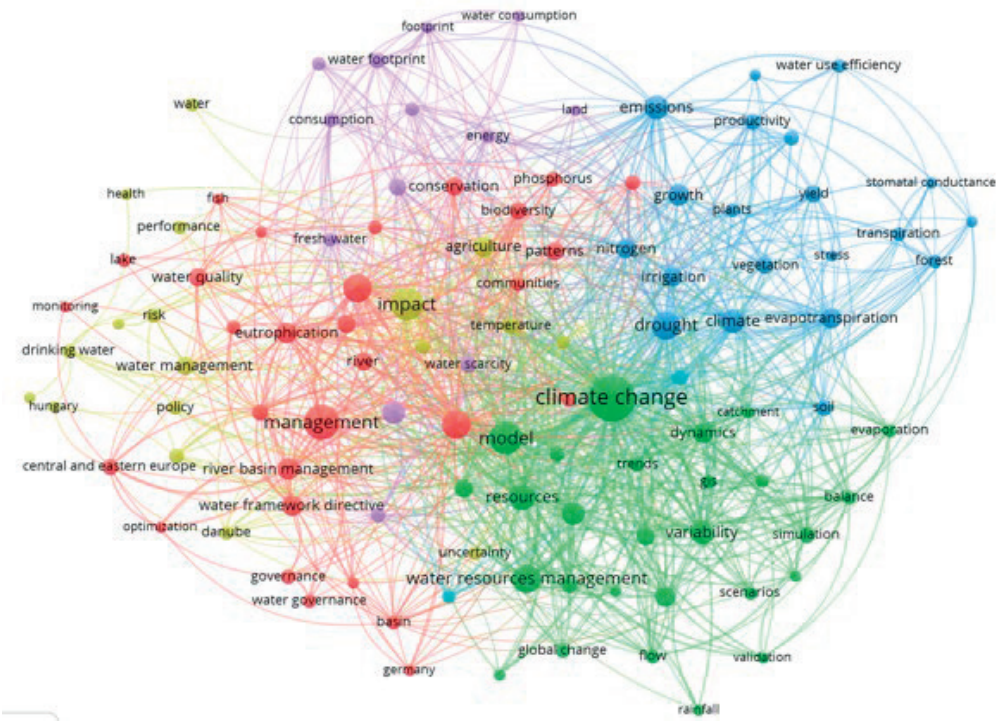

Figure 5. The affiliation map based on keywords
(* minimum number of documents of a country = 5)

CONCLUSIONS

Water management is an actual topic in research and the EU agenda underlines the urge to find innovative ways to recover water and accelerate the switch from the linear moder to the circular one. The present bibliometric analysis showed the research in the field is encouraged more by the impact of the socio-economic factors and climate change issues than by the legislative framework. This tendency illustrates the research related to the use of water resources in various field is dependent on previous studies and the scientific production has in general a gradual increase.

Regardless, water management is an actual trend in research, there is less interest in studying the use of water resources in CEE countries, despite their focus on agriculture and the need for irrigation, than in other EU regions, like the Mediterranean area. This can be noticed from the limited studies in the field that concentrated the present study on 390 documents. Even though the present study illustrates the research trends in a specific EU area, the highest research interest for this region comes from developed countries like Germany and USA and less from the CEE countries. Poland was the only CEE country that recorded a significant number of research documents that investigated the use of water resources in the region. Moreover, the strongest research institutions in terms of scientific production are mainly located in countries from other geographical regions than from CEE area. This illustrates that research related to the water use doesn't depend on the geographical aspects and the results are useful for the stakeholders from another region too.

Ultimately, the transition towards a circular economy in water management requires a multifaceted approach that integrates technological innovations, policy frameworks, and stakeholder engagement.

While the progress in Central and Eastern Europe is promising, significant barriers still exist, including outdated infrastructure, limited financial resources, and regulatory challenges. Overcoming these barriers will require a

multifaceted approach, involving the collaboration of policymakers, researchers, and industry stakeholders.

The research related to water use in CEE region focus on specific topics like agriculture, climate-change consequences, water management, water governance and the need of change and adaptation in the field. The most mature interest in research is related to the agriculture field which shows that the change in assuring circularity in water use should start from this sector. Moreover, the other research topics that are grouped in clusters are highly linked to the agriculture. For example, the cluster that contains aspects about the impact of climate change on the water use has items that describe activities with impact on agriculture, like drought or irrigation. This indicates that on the one hand, the stakeholders from this region should concentrate their efforts to other activities also, as increasing the awareness of the involved population. On the other hand, it shows the highest problems in this region about the water use and availability are in agriculture.

The lack of direct interest on the impact of water uses on the labour market in the context of the new changes of the Green Deal Program and circular economy adoption shows the progress in using sustainable ways to treat water is still low. Such a switch would bring new requirements for the employees as green jobs involves new skills and a high capacity of adaptation. As no cluster illustrates a direct interest in this regard, it is clear that the circularity in water management is still at the beginning and Academia should focus more on this topic.

The present research has several limitations. Firstly, the study is based on the selection of articles and proceeding from only one database. Secondly, the research didn't consider reports and legislative documents that would give a more comprehensive image about the use of water resources in CEE region. In order to complete the present results and to offer the stakeholders a more complex image on the topic, the future research will analyse the results from more bibliometric databases (ex: SCOPUS and PubMed) and will complete the analysed documents with reports, legislative frameworks and case studies.

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