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THEORETICAL APPROACHES TO REDUCE WATER LOSSES IN IRRIGATION CHANNELS AND BIBLIOMETRIC ANALYSIS OF SCIENTIFIC RESEARCH.

A. Arifjanov
A. Fatxulloyev
D. Bakhromova
H. Yuldosheva
M . Gafforova

Annotatsiya. Sug‘orish kanallaridagi suv yo‘qotishlari, ayniqsa iqlim o‘zgarishi, qishloq xo‘jaligida suvga bo‘lgan talabning ortishi va chuchuk suv resurslarining cheklanganligi sharoitida, global suv resurslarini boshqarishdagi eng dolzarb muammolardan biri hisoblanadi. Ushbu tadqiqotning maqsadi suv yo‘qotishlarini kamaytirishning nazariy yondashuvlari va muhandislik yechimlarini tahlil qilish hamda bibliometrik tahlil orqali ushbu yo‘nalishdagi ilmiy taraqqiyotni baholashdan iborat. Tadqiqot uchun Web of Science va Scopus ma’lumotlar bazalaridan 2000–2024-yillar oralig‘ida chop etilgan 754 ta ilmiy maqola to‘plandi. Nashrlar dinamikasi, geografik taqsimoti, yetakchi mualliflar, ilmiy hamkorlik tarmoqlari va kalit so‘zlar klasterlarini o‘rganish uchun VOSviewer dasturi yordamida bibliometrik usullar qo‘llanildi. Natijalar ilmiy faoliyatning barqaror o‘sib borayotganligini ko‘rsatdi. Eng katta ilmiy hissalar Xitoy, Amerika Qo‘shma Shtatlari va Buyuk Britaniya hissasiga to‘g‘ri keladi. So‘nggi tadqiqotlarda geomembranalar, polimer qoplamalar, sun’iy intellekt modellari hamda ilg‘or sonli modellashtirish usullari sizib chiqish (filtratsiya) yo‘qotishlarini kamaytirish va gidravlik samaradorlikni oshirishning samarali vositalari sifatida e’tirof etilgan. Mazkur bibliometrik tahlil an’anaviy muhandislik usullaridan gidravlika, materialshunoslik va raqamli texnologiyalarni birlashtirgan kompleks, innovatsion yondashuvlarga o‘tish jarayonini yoritib beradi. Tadqiqot natijalari siyosatchilar, muhandislar va olimlar uchun barqaror sug‘orish tizimlarini loyihalash, suvdan foydalanish samaradorligini oshirish hamda kelajakdagi ilmiy tadqiqotlar ustuvor yo‘nalishlarini belgilashda amaliy ahamiyat kasb etadi.

Kalit so‘zlar: sug‘orish kanallari, suv yo‘qotishlari, gidravlik samaradorlik, kanal qoplamalari, filtratsiyani nazorat qilish, bibliometrik tahlil.

Annotation. Water losses in irrigation canals remain one of the most pressing challenges in global water resources management, particularly under conditions of climate change, increasing agricultural demand, and limited freshwater availability. This study aims to analyze theoretical approaches and engineering solutions for reducing water losses while mapping scientific progress in this field through bibliometric analysis. A comprehensive dataset of 754 articles published between 2000 and 2024 was retrieved from the Web of Science and Scopus databases.

Bibliometric techniques, supported by VOSviewer software, were applied to examine publication dynamics, geographical distribution, leading authors, collaboration networks, and keyword clusters. The results demonstrate a steady growth of scientific activity, with the most significant contributions coming from China, the United States, and the United Kingdom. Recent studies emphasize the use of geomembranes, polymer linings, artificial intelligence models, and advanced numerical simulations as effective strategies for seepage control and hydraulic efficiency enhancement. This bibliometric synthesis highlights the transition from traditional engineering methods to integrated, technology-driven approaches that combine hydraulics, materials science, and digital tools. The findings provide guidance for policymakers, engineers, and researchers in designing sustainable irrigation systems, improving water use efficiency, and setting future research priorities.

Keywords: irrigation canals, water losses, hydraulic efficiency, canal lining, seepage control, bibliometric analysis

Аннотация. Потери воды в ирригационных каналах остаются одной из наиболее актуальных проблем в глобальном управлении водными ресурсами, особенно в условиях изменения климата, растущего сельскохозяйственного спроса и ограниченной доступности пресной воды. Цель данного исследования — проанализировать теоретические подходы и инженерные решения для снижения потерь воды, а также оценить научный прогресс в этой области с помощью библиометрического анализа. Для анализа был использован обширный набор данных, включающий 754 статьи, опубликованные в период с 2000 по 2024 год, из баз данных Web of Science и Scopus. Библиометрические методы, поддерживаемые программным обеспечением VOSviewer, были применены для изучения динамики публикаций, географического распределения, ведущих авторов, сетей сотрудничества и кластеров ключевых слов. Результаты демонстрируют устойчивый рост научной активности, при этом наиболее значительный вклад вносят Китай, США и Великобритания. В последних исследованиях особое внимание уделяется использованию геомембран, полимерных облицовок, моделей искусственного интеллекта и передовых численных симуляций в качестве эффективных стратегий контроля фильтрации и повышения гидравлической эффективности. Анализ совместной встречаемости ключевых слов выявил исследовательские кластеры, посвященные технологиям облицовки каналов, седиментации, цифровому мониторингу и энергоэффективному управлению водными ресурсами. Данный библиометрический анализ освещает переход от традиционных инженерных методов к интегрированным, технологически ориентированным

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подходам, сочетающим гидравлику, материаловедение и цифровые инструменты. Полученные результаты служат руководством для политиков, инженеров и исследователей при проектировании устойчивых ирригационных систем, повышении эффективности использования воды и определении приоритетов будущих исследований.

Ключевые слова: ирригационные каналы, потери воды, гидравлическая эффективность, облицовка каналов, контроль просачивания, библиометрический анализ

INTRODUCTION.

Global problems of water resources management, in particular, reducing water losses in irrigation systems and ensuring the sustainable operation of existing hydraulic structures, have become one of the main directions of modern engineering research. Against the backdrop of growing demographic pressure, increasing water demand in agriculture, and climate change, modernizing hydraulic systems, enhancing energy efficiency, and controlling seepage are urgent tasks. In this regard, developments aimed at modernizing existing facilities without disrupting them are of particular importance. The parallel-mode incremental upgrade approach proposed by Dimmitt (2004) is a major breakthrough in ensuring service continuity in existing systems, and this approach forms an important model for industrial infrastructures.[1]

Research is expanding into the use of geomembranes, geosynthetics, and modern polymer materials to eliminate seepage, a major cause of water loss in irrigation systems. The effectiveness of geomembrane and geotextile covers has been demonstrated experimentally and through modeling by Scuero and Vaschetti (2019), Al-Mashaqbeh (2023), and Hamed et al. (2017). Louati et al. (2023) and Liu et al. (2023) evaluated the hydraulic effects of different pavement configurations using numerical simulation tools (COMSOL, CFD).[2][3][4][5][6] These approaches allow for precise analysis of the complex balance between soil and water. At the same time, the study by Wu et al. (2022) also examined the chemical stability and environmental safety of modern polymer materials.[7]

Numerical and theoretical modeling methods are taking a leading role in improving the effectiveness of seepage control. Yuan et al. (2019) analyzed the stress-strain distribution based on Finite Element Analysis to reduce water loss through reinforced concrete channel linings.[8] In cold regions, mathematical models developed by Wang et al. (2019) and Ge et al. (2020) integrated temperature, freezing cycles, and soil-water interactions. Ouyang et al. (2021) estimated hydraulic conductivity based on laboratory and numerical modeling, while Gates and Alshaikh (1993) used a stochastic approach to account for climatic and hydrological uncertainties in design.[9][10][11][12]

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In recent years, artificial intelligence-based technologies have begun to play a significant role in monitoring and evaluation systems. Eltarabilly et al. (2023) demonstrated the ability of machine learning models such as Random Forest, ANN, and SVR to predict water losses in unlined irrigation canals with high accuracy.[13] Chen et al. (2018) proposed advanced solutions for real-time water consumption detection using non-contact radar technology (Surface Velocity Radar). [14] These methods are relevant for automating monitoring systems, saving resources, and providing timely technical maintenance of facilities.

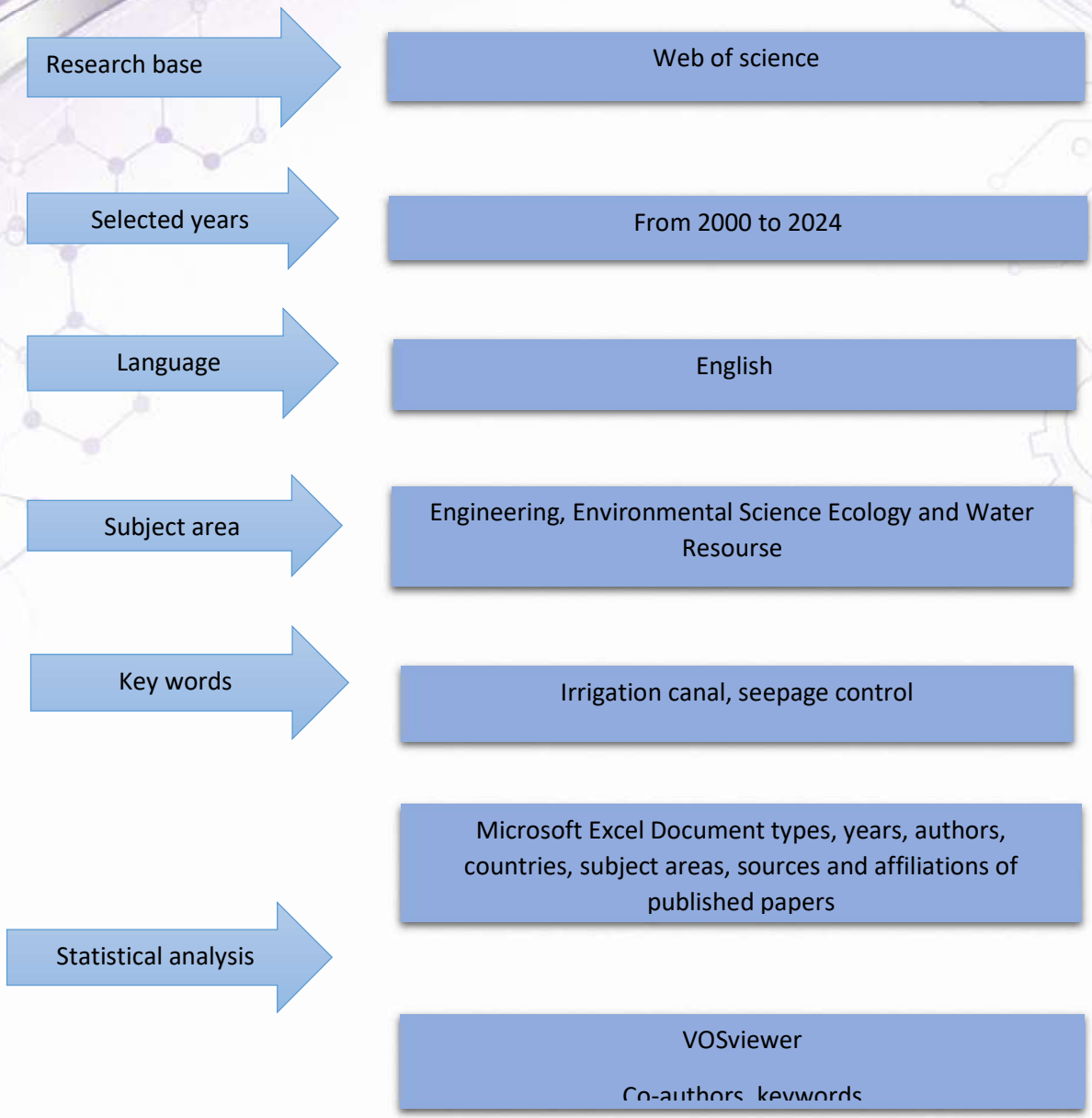
Theoretical foundations also play an important role in improving the hydraulic efficiency of irrigation systems. Ramírez-Luna et al. (2009) revealed the effects of different geometric shapes on flow by modeling water distribution based on Reynolds equations. Ghimire et al. (2022) compared the hydraulic performance of lined and unlined canals in Nepal and found that there were significant losses in unlined canals. A comprehensive literature review by Singh et al. (2020) provides a comprehensive overview of the hydraulic efficiency, economic benefits, and environmental characteristics of various coating technologies.

Dredging is also being studied separately as an important component of water infrastructure. The article ANON (1996) analyzes the global importance of dredging technologies in ensuring the navigational safety of ports and sea channels, their engineering and environmental aspects. The hydrograph motion methodology based on inflow and outflow flows proposed by Chai et al. (2015) is one of the simplest and most effective approaches to streamflow estimation.

In conclusion, the above scientific developments are shaping integrated, technologically and environmentally sustainable approaches to improve the overall efficiency of modern irrigation and water transfer systems. These studies have proven that the reliability of water infrastructure can be improved by combining methods such as geomembranes, polymer materials, artificial intelligence models, stochastic design, and modeling technologies. This research project aims to deeply analyze these approaches, assess their advantages and limitations, and develop optimal engineering solutions.

THEORETICAL METHODS: Some studies have emphasized the need for an integrated approach to the design of irrigation canals to ensure their technical and economic feasibility and to guarantee the long-term and sustainable operation of pumping stations. In particular, maintenance efficiency can be improved by properly selecting aggregates, continuously monitoring the turbidity level in the flow coming from the water source, and assessing the condition of water intake facilities. This approach ensures the continuity of pumping stations' operations and significantly extends their service life.

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An analysis of the international scientific databases Scopus and Web of Science shows that a total of 720 scientific articles and research papers on improving the efficiency of irrigation canals were published between 2000 and 2023. These figures clearly demonstrate the global relevance of the topic; its role in ensuring resource efficiency and environmental sustainability is increasing year by year (Figure 1).

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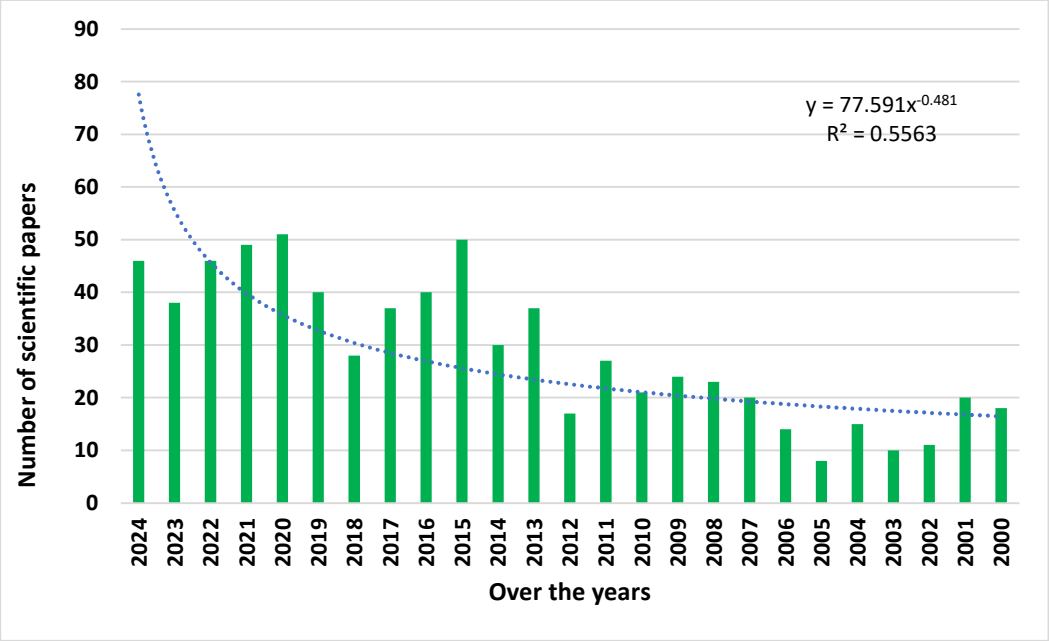


Figure 1 Number of scientific papers published in the Web of Science database by year

Analysis of the Web of Science database, recognized by the global scientific community, shows that over the past five years, the number of scientific articles and developments related to water losses in irrigation canals, hydraulic efficiency, and coating technologies has increased significantly. This growth trend, in turn, reflects the global relevance of the topic, climate change, resource scarcity, and increasing demands for infrastructure reliability. According to the results of the analysis, in-depth and systematic research conducted in this area, especially by leading universities and scientists from the People's Republic of China, the USA, and the UK, has taken the lead. At the same time, scientific activity of Uzbek scientists in the field is also observed, which reflects the importance of the issue in the regional context and integration in the international scientific arena (Figure 2).

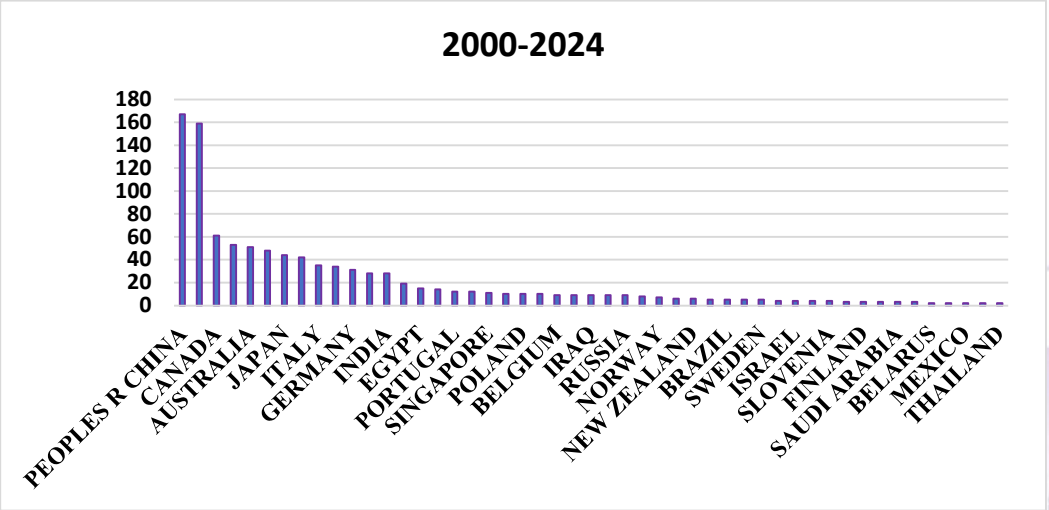


Figure 2 The number of scientific works by country from 2000 to 2024 in the Web of Science database

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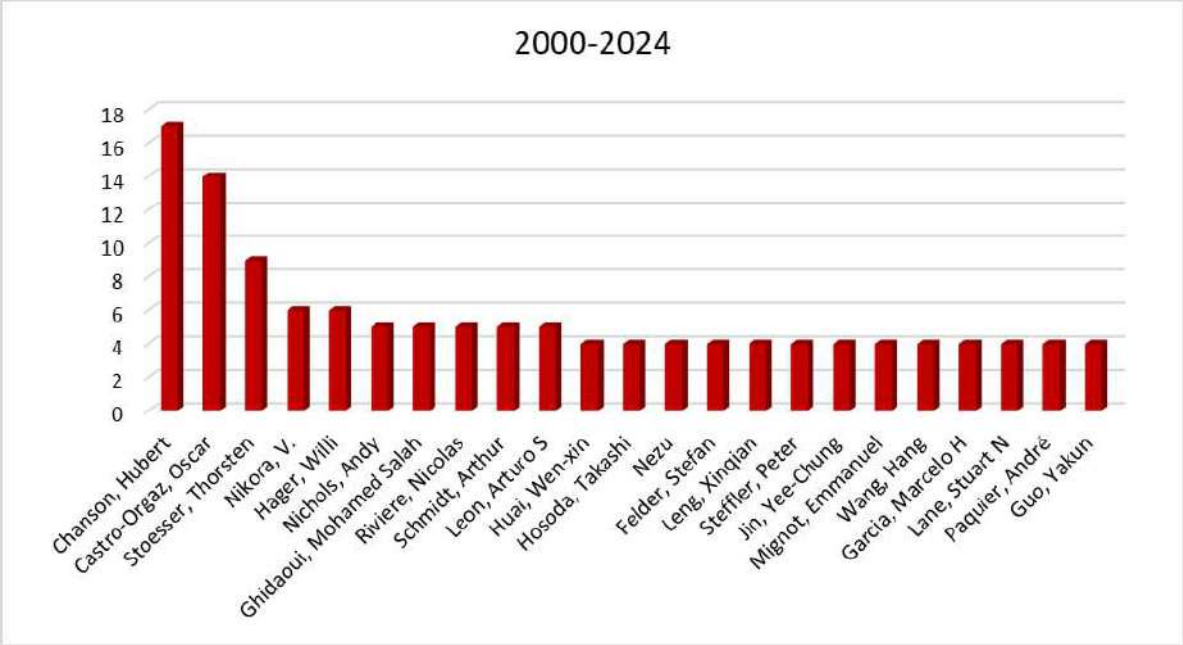


Figure 3 Number of scientific works by authors from 2000 to 2024

In particular, ensuring high hydraulic efficiency and reliability of irrigation canals, their long-term, loss-free and stable operation, as well as the economical and rational use of existing water resources are considered one of the most pressing scientific and technical problems on a global scale today. Research in this area is being conducted in close integration with various interdisciplinary fields, including not only the field of hydraulic engineering, but also ecology, energy, geoinformatics, and digital technologies.

Scientific research conducted by leading scientific centers and international research institutes is based on modern modeling, theoretical and experimental approaches and is aimed at increasing the sustainability of irrigation systems, minimizing water losses, and ensuring their environmental and energy efficiency. At the same time, the technical condition of irrigation facilities is constantly monitored through innovative technologies and digital monitoring systems developed by advanced scientists, which allows them to further increase their operational life and efficiency.

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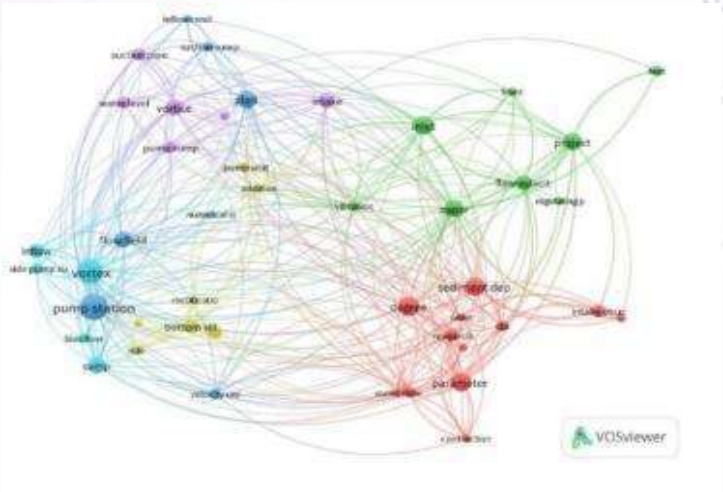


Figure 4. Scientific analysis conducted using VOSviewer software. (keywords)

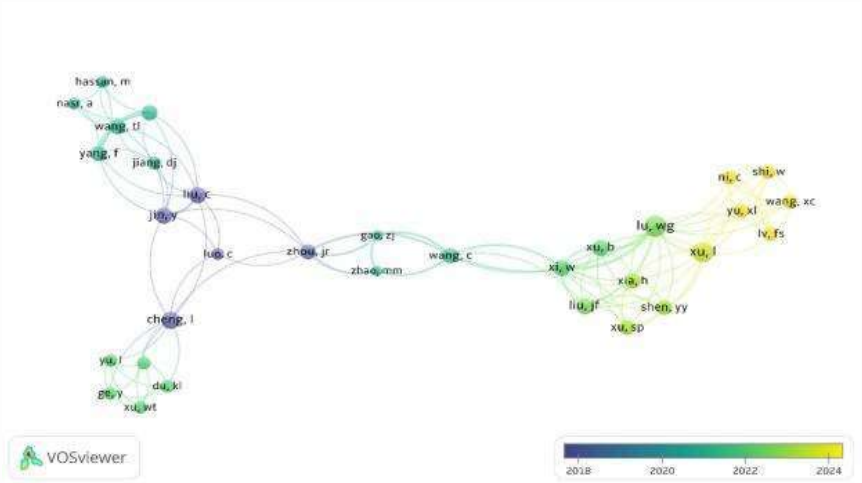


Figure 5 Scientific analysis conducted in VOSviewer.

By importing a collection of publications from leading bibliographic databases such as Web of Science into VOSviewer, it is possible to conduct a multi-criteria and systematic analysis of scientific activity on a topic. Network visualizations based on VOSviewer algorithms identify scientific collaborations between authors, publication activity of research organizations, leading scientific journals and their specialization by subject, and levels of scientific activity at the country level. Also, based on keywords and their frequency of occurrence, topic clusters are identified and current scientific directions, conceptual connections, and emerging research trends in the field are identified. This approach is not limited to traditional bibliographic indicators (number of publications, citations, h-index), but allows for in-depth analysis of the flow of scientific knowledge, identification of influential scientific centers, and creation of a structural map of the research field.

The analysis results are shown in Figures 4 and 5 , which visually represent the keyword clusters and author collaboration network generated using VOSviewer. These visual analyses reveal the groups around which scientific

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research on a topic is formed, who is conducting it, and their place in the global scientific community.

DISCUSSION The bibliometric findings highlight several important trends in the scientific development of this field. First, the accelerating growth of publications since 2010 reflects both the urgency of water scarcity and the rapid introduction of new technologies. The leadership of China, USA, and UK aligns with their significant investments in irrigation modernization, while the increasing contributions from Uzbekistan and Central Asia underscore the regional importance of the issue.

Second, the keyword clusters confirm that the field is transitioning from traditional methods—such as dredging and conventional linings—to advanced materials, artificial intelligence, and digital monitoring tools. This indicates a paradigm shift toward multidisciplinary research combining hydraulics, materials science, and data analytics.

Third, the collaboration networks suggest that while international cooperation is increasing, research remains regionally concentrated. Stronger global partnerships are needed to transfer knowledge and adapt solutions to different hydrological and socio-economic contexts.

Finally, the results emphasize that future progress depends on integrating technical innovations with sustainability goals. Approaches such as AI-based monitoring, energy-efficient canal rehabilitation, and climate-adaptive hydraulic models will play a key role in ensuring long-term irrigation efficiency.

CONCLUSION: Increasing the hydraulic efficiency of irrigation canals and effectively cleaning them from sediment layers are among the pressing problems. An analysis of scientific articles published in the Scopus and Web of Science databases from 2000 to 2024 shows that today the main scientific research is being conducted in the areas of hydraulic stability of the flow, effective separation of sediments, as well as the development of energy-efficient technologies.

The results of the research confirm that to increase the overall efficiency of irrigation canals, it is necessary to optimize the flow velocity distribution, accurately model the sedimentation trajectories of river effluents, and introduce automated and energy-saving methods of cleaning processes. In particular, it is possible to significantly extend the service life of structures by deeply studying the physical, mechanical, and chemical composition of effluent fractions and developing appropriate technologies, especially under changing hydraulic conditions along the channel.

International experience, in particular, advanced scientific developments carried out in China, the USA, and the UK, serve as an important example in this direction. At the same time, Uzbek scientists have also been conducting important

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research in this area in recent years and developing practical solutions. This is of great importance not only for increasing the efficiency of irrigation systems, but also for integrated water resource management, ensuring environmental safety, and increasing energy efficiency.

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