remote sensing

Review

Review Analysis of Irrigation and Application of Remote Sensing in the Lower Mekong River Basin

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Abstract: Irrigated agriculture is indispensable to the Lower Mekong River Basin (LMB), which ensures food security and provides livelihoods for tens of millions of people. Irrigation, agricultural production, hydropower and aquatic ecosystem health are intertwined in LMB, so it is necessary to adopt a holistic approach to analyze irrigation problems. Here, we discuss the challenges and opportunities of LMB irrigation. Bibliometric analysis is carried out to determine the characteristics and patterns of watershed irrigation literature, such as the importance of authors, affiliated institutions, and their distribution in China. Based on bibliometric analysis, research topics are determined for thematic review. Firstly, we investigated the factors that directly affect the demand and supply of irrigation water and associated crop yield impacts. Secondly, we analyzed the influence of water availability, land use and climate change on agricultural irrigation. Thirdly, we analyzed the adverse effects of improper irrigation management on the environment, such as flow pattern change, ecosystem deterioration and land subsidence caused by groundwater overexploitation. Fourthly, the time–space mismatch between water supply and demand has brought serious challenges to the comprehensive water resources management in cross-border river basins. In each specific application area, we sorted out the technologies in which remote sensing technology is used. We hope that this review will contribute to in-depth research and decision analysis of remote sensing technology in agricultural irrigation.

Keywords: bibliometric analysis; irrigation; agriculture; Lower Mekong River Basin; water resource management; remote sensing

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1. Introduction

Stretching over 4900 km from the Tibetan Plateau to the South China Sea, the Mekong River drains an area of 795,000 km^2 and has an average annual discharge of 475 km^3. The Lower Mekong River Basin (LMB, Figure 1) includes parts of Cambodia, Lao PDR, Thailand and Vietnam, and it is home to more than 70 million people [1]. The distribution of precipitation in the LMB has a strong seasonality, which plays a decisive role in the selection of local crops and planting dates in different areas within the region [2]. In LMB countries, the wet season runs approximately from May to October, followed by a dry season from November to March. The Mekong River flow usually is at its lowest in April.

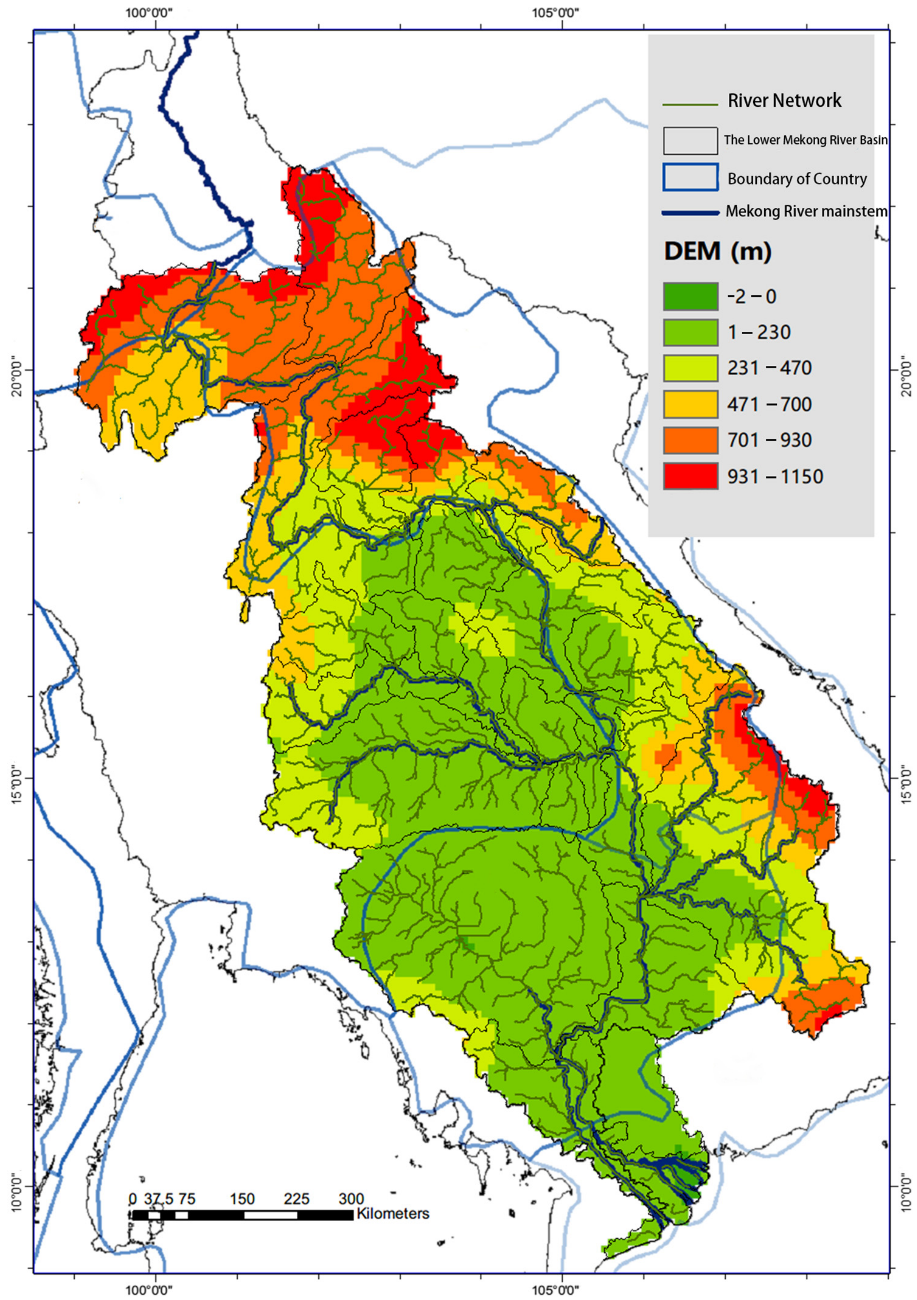

Figure 1. Mekong River topographic map.

Rural livelihoods in the LMB are highly dependent on agriculture [2]. This is particularly true for Cambodia, Myanmar and Laos PDR where agriculture related activities account for a significant share of GDP as shown in Table 1. Gross domestic product (GDP) is a monetary measure of the market value of all the final goods and services produced in a specific time period by a country. Irrigation plays an important role in securing monsoon crops and converting a single crop, namely rain-fed rice, to multiple cropping systems. Irrigation in the LMB relies on water diverted from the Mekong main stem and its tributaries. Irrigation is mostly carried out in the dry season when crop area is lower than that during the rainy season. Notably, the Mekong Delta is the most productive area in the LMB and a main irrigation water consumer. Crops in the LMB are heavily dependent on rainwater to grow, with rice being the dominant crop. The LMB produced 48.2 million tons, or around 51% of the 93.6 million tons of rice produced in the four LMB countries (Lao PDR, Cambodia, Thailand, and Vietnam) as a whole in 2013 [3].

Table 1. Key statistics in the LMB countries, 2021.

	Cambodia	Lao PDR	Thailand	Vietnam	Myanmar
GDP (10^6 USD)	26,961	18,827	505,947	366,137	65,091
Agriculture, forestry, and fishing, value added (% of GDP)	22.8	16.1	8.5	12.6	23.4
Population (10^3)	16,589	7425	71,601	97,468	53,798
GDP Growth (%)	3.0	2.5	1.5	2.6	−17.9
GDP per capita (USD)	1625	2535	7066	3756	1209
Urban population growth rate (%)	2.9	3.2	1.6	2.7	1.7
Poverty (%)	16.7	27.6	9.8	2.8	25.6

Source: https://data.worldbank.org/ (accessd on 15 March 2023).

In general, irrigation is seen as a crucial component of rural development and plays a significant role in boosting agricultural production and alleviating poverty in the LMB countries [4]. So far, irrigation systems are created expressly to produce rice, making it challenging for farmers to switch to other crops [4]. Nevertheless, the intensification of irrigated agriculture had led to farmers in Thailand and Vietnam to shift from rice to high-return activities such as aquaculture or cash crops. Nowadays, however, a considerable number of populations in the LMB still live in poverty, as shown in Table 1.

Water abstraction for agriculture makes up around 90% of all water diversions in the region (Cambodia: 94%, Thailand: 91%, Vietnam: 86% and Laos: 82%) [4]. However, the distribution of water resources in the Mekong River region is rather uneven, and there exist competing interests in water uses between the upper and lower reaches. Water is essential for sustainable agricultural production [5,6]. In agricultural water use, irrigation has the largest share, and irrigation efficiency and grain yield directly affect a country's agricultural development level [7,8].

Meanwhile, water, food and energy (WEF) are highly interconnected in the LMB. For example, water is used to produce food and energy (e.g., irrigation and hydropower) [9], and in return, energy is required to pump and distribute water and produce food [10,11]. In fact, irrigation uses large amounts of water, which poses a challenge to water resources management in the LMB, especially in the dry season. In this situation, it is useful to take a holistic perspective by considering water, food and energy simultaneously, or in other words, taking a WEF nexus perspective while analyzing irrigation in the LMB. Such a perspective can potentially enhance water, energy and food security by increasing efficiency, reducing trade-offs, building synergies and improving governance across the three interconnected sectors [12]. Needless to say, WEF represents the most significant resources that support sustainable development of human society [13].

Most existing studies [14–17] related to irrigation in LMB focus on hydropower because of the close relationship between these two sectors. There are both synergies and tradeoffs between these two sectors. For instance, water stored in upstream hydropower reservoirs can augment irrigation water supply in the downstream during the dry season and in dry years, effectively relieving downstream drought. More enhanced cooperation between the riparian countries are expected to be an effective way in addressing water and food challenges in the LMB [18]. On this important and complex issue about irrigation in the LMB, despite a considerable number of existing studies conducted from various angles, there is generally a lack of systematic review of the development, status and future challenges of irrigation in the region, especially when it is related to the interactions and interdependencies between irrigation and other water-using sectors such as hydropower and ecosystem. To the best of our knowledge, an irrigation-focused review is yet to be done for the LMB. Based on a detailed investigation of available publications focusing on this topic through bibliometric analysis and specific theme-focused review, this paper aims to improve our understanding of key challenges and opportunities in irrigation management and development in the LMB.

2. Methodology

2.1. Data Collection

The bibliometric analysis and review in this paper rely on literature on LMB irrigation found from the Web of Science database [19]. We chose the Web of Science because it is the most well-established bibliometric dataset, and the inclusion criteria for journal titles are transparent and being regularly updated. The Web of Science database has synthetical and integrated paper records [20]; the high number of journals and articles in its collection permitted us to generate representative results.

Firstly, bibliometric records can be constructed using a keyword such as "irrigation Mekong" in the title, the abstract or the keyword of publications searching in Web of Science [21]. Secondly, we used key words such as land use, crop productivity and land cover in the search query associated with "irrigation Mekong". Thirdly, we used "Food, Water and Energy Nexus" and its variants (Water, Food and Energy Nexus; Energy, Food and Water Nexus, etc.) [22] to search for related publications in the Web of Science. In addition, we also use some search wildcards and similar keywords to increase the scope of the search. Overall, the summary of searching keywords includes "Irrigation, Mekong, land use, crop productivity, land cover, Food water and Energy Nexus". Lastly, after going through the search, we exported the text documents of those identified publications from the Web of Science and put them into the Citespace for bibliometric analysis.

2.2. Data Preprocessing

A screening of the collected articles from the Web of Science suggested that some publications not related to the topic were included, and they were subsequently removed from the collection after double-checking those publications from the original websites where they were published online, if applicable. We then extracted the information of each author's country of origin, affiliations, year of publication, publisher and citation numbers. For the purpose of thematic analysis, we extracted the main research content from the title and abstract of each paper for further analysis [23].

2.3. Bibliometric Analysis

Bibliometric analysis is effective in analyzing research conducted in a specific research field with a large amount of data. It helps discover the evolution of research activities in a specific field and can also help identify emerging areas in that field [24]. The bibliometric analysis was conducted using publications searched from the Web of Science database.

This paper is based on visual analytic functions executed in a bibliometric analysis software called Citespace [25]. Citespace is a java-based bibliometric analysis software tool to visualize and analyze temporal and structural patterns in scientific literature [26]. To obtain the required results, we set parameter thresholds in the software, following its instructions. The software has been constantly updated in recent years to accommodate various research objectives for visual analytic tasks [25]. In this study, we used Citespace 5.8.R3 (64 bit) [27].

2.4. Thematic Analysis

In addition to the bibliometric analysis, we identified several major research hotspots in irrigated agriculture in the LMB—for example, climate change, environmental issues, human alterations to flow regime due to hydropower generation, the impact of irrigation water diversion on downstream water uses and ecosystem health and so forth. The positive impacts of hydroelectric power reservoirs are also explored. In addition, we also evaluate transboundary water resource management across riparian countries from the perspective of the WEF nexus.

Figure 2 illustrates the organization of the study presented in this paper. First, we established a literature dataset. Second, we conducted a bibliometric analysis to identify, categorize and prioritize topics of high relevance and importance regarding irrigation in the LMB. It also categorizes the institutions and countries of the leading authors who wrote those articles. Third, with these findings, a thematic review was also carried out, focusing on each of the four identified areas. The bibliometric analysis identifies the patterns of the literature, whereas thematic review moves one step further to explore key issues under each selected theme. This review aims to tap into recent publications on irrigation in the LMB to produce a systematic review on key issues regarding irrigation in the basin.

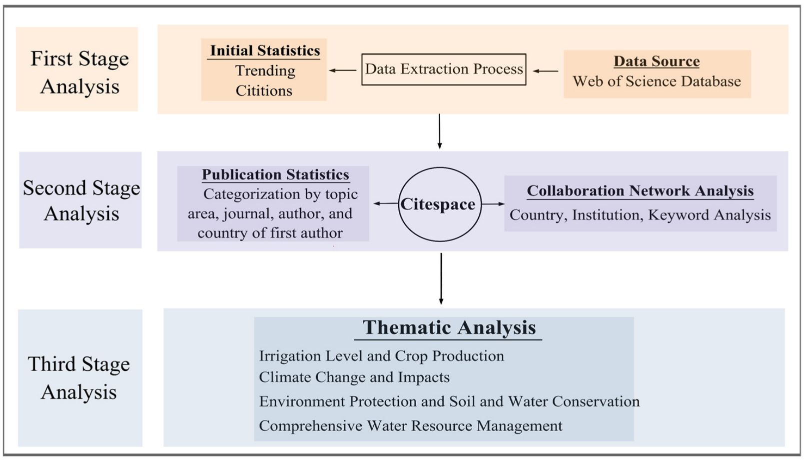

Figure 2. Overall organization of review of LMB irrigation.

3. Bibliometric Analysis Results

3.1. Literature Statistics

A total of 270 publications related to irrigation in the LMB were chosen from the body of literature extracted from the Web of Science database, after manually excluding publications that are not related to the research topic. The bar chart of Figure 3 shows the number of published articles per year, which has an increasing trend from 2000 to 2021. In 2019, there were over 35 publications related to irrigation in the LMB. The number of publications is still rather low, considering the importance of this topic. The line on Figure 2 shows citations of those publications, which has been rapidly increasing since 2006.

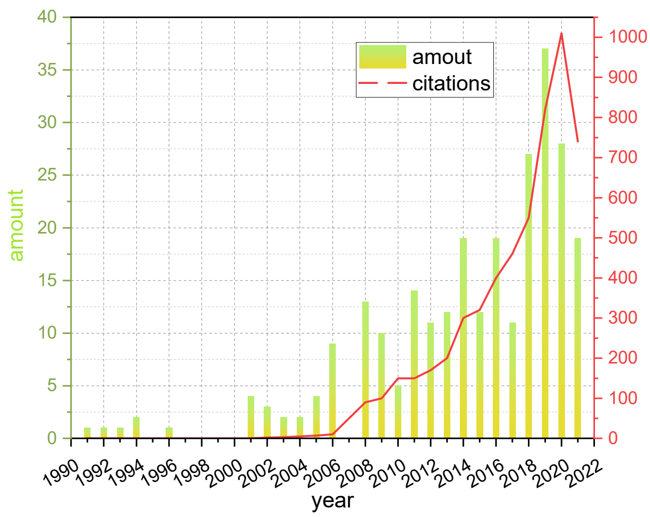

Figure 3. The number of publications and citations related to irrigation in the LMB.

Table 2 shows that most of the dataset's publications are centered on environmental sciences, ecology, agriculture, water resources and plant sciences. Most articles about irrigation in the LMB focus on ecological and environmental, agricultural and water resources aspects. The Mekong River's water crisis has long been a major regional issue [28,29]. Furthermore, some articles [30–32] also analyzed irrigation from the regional economic point of view.

Table 2. Statistical results in research areas of the selected dataset.

Research Areas	Record Count	% of 270
Environmental Sciences Ecology	189	70.0%
Agriculture	167	61.9%
Water Resources	162	60.0%
Plant Sciences	100	37.0%
Meteorology Atmospheric Sciences	78	28.9%
Marine Freshwater Biology	76	28.2%
Biodiversity Conservation	68	25.2%
Geography	65	24.1%
Business Economics	61	22.6%
Science Technology Other Topics	61	22.6%
Engineering	59	21.9%
Mathematics	50	18.5%
Energy Fuels	41	15.2%
Geochemistry Geophysics	40	14.8%
Oceanography	40	14.8%
Physical Sciences Other Topics	37	13.7%
Geology	36	13.3%
Public Environmental Occupational Health	36	13.3%
Fisheries	30	11.1%
Food Science Technology	25	9.3%

Table 3 shows the distribution of those selected 270 articles in various academic journals. Most of the articles were published in agriculture-related journals even though they were widely distributed. Several journals, such as *Water*, *Agricultural Water Management*, *Field Crops Research*, *Advances in Global Research*, *Paddy and Water Environment*, and *Science of The Whole Environment* published more papers on LMB irrigation than other journals.

Table 3. Journal-wise distribution of the selected articles.

Journal	Impact Factor (2021)	H-Index (2021)	Average Number of Citations per Paper (2021)	Record Count	Share in Total Number of Selected Publications
Water	3.530	69	7.91	9	3.3%
Agricultural Water Management	6.611	139	13.67	7	2.6%
Field Crops Research	6.145	161	19.56	7	2.6%
Advances in Climate Change Research	4.746	30	5.93	6	2.2%
Paddy and Water Environment	1.554	38	9.24	6	2.2%
Science of The Total Environment	7.963	221	6.29	6	2.2%
Hydrological Processes	4.015	128	27.12	5	1.9%
International Journal of Remote Sensing	2.581	106	10.47	5	1.9%
Remote Sensing	5.076	161	25.19	5	1.9%
Water International	2.22	57	9.48	5	1.9%
Ambio	4.022	97	23.87	4	1.5%
Food Security	4.603	62	16.42	4	1.5%
Frontiers in Environmental Science	5.646	48	8.22	4	1.5%
Journal of Health and Pollution	2.249	10	4.82	4	1.5%
Journal of Hydrology	4.646	203	36.90	4	1.5%
Applied Geochemistry	3.621	121	24.86	3	1.1%

In addition, we also summarized countries of origin of the authors' affiliations (Table 4) and the highly cited papers, as shown in Table 5. Table 4 shows that 27.8% of the first authors of the selected publications are from Vietnam, 20.9% from the United States, 18.9 from Japan, 17.0% from Australia, 13.7% from China and 10.7% from Cambodia. This implies that irrigation in the LMB has drawn broad attention beyond riparian countries in the region.

Table 4. Countries of origin of authors.

Country	Paper Record Count	% of 270
Vietnam	75	27.8%
United States of America	59	21.9%
Japan	51	18.9%
Australia	46	17.0%
P.R. China	37	13.7%
Cambodia	29	10.7%
Laos	24	8.9%
Thailand	23	8.5%
Germany	18	6.7%
Netherlands	15	5.6%
England	10	3.7%

Table 5. Citations of the selected publications on LMB irrigation.

Publication	Average per Year	Total
Matthew L. Polizzotto [33]	30.6	429
Laurent Charlet [34]	13.4	214
Toshihiro Sakamoto [35]	12.4	198
Ingjerd Haddeland [36]	11.3	181
N.T. Sona [37]	16.8	168
Toshihiro Sakamoto [38]	14.0	168
Polya, DA [39]	9.8	167
Matti Kummu [40]	10.8	151
Benjamin D. Kocar [41]	9.6	135
F. Su [42]	18.3	110
Mauricio E. Arias [43]	13.1	105
Jory S. Hecht [44]	34.3	103
Nguyen Minh Dong [45]	9.9	99
Mauricio E. Arias [46]	9.3	93
Nguyen-Thanh Son [47]	10.8	86
Chandrashekhar M. Biradar [48]	7.3	80
Thi Thu Ha Nguyen [49]	7.9	79
Shawn G.Benner [50]	5.4	76
Gert-Jan Wilbers [51]	9.4	75
Toshihiro Sakamoto [52]	5.6	73

Table 5 lists the average number of citations per year and the total number of citations of highly cited publications on LMB irrigation, in descending order. The number of citations can explain the influence of an article in the field of the subject. At the same time, the number of citations has a close relationship with the quality of periodicals. The first few articles with a high number of citations focus on irrigation-related environmental issues in the Mekong River basin, the spatiotemporal distribution of rice phenology and cropping systems, the effects of irrigation, agriculture drought and so on.

3.2. Collaboration Analysis

Citation networks and co-citation networks have been long studied in information science and other disciplines [53]. Co-citation relations serve as a fundamental grouping mechanism [54]. We used Citespace to generate collaboration network graphs, as shown in Figure 4. In Figure 4a,b, we examined the distribution of research institutions and countries that the authors were affiliated with at the time those articles were published. The size of each node represents the number of citations to the corresponding article in this dataset. The theme of each cluster of cited articles is algorithmically labeled.

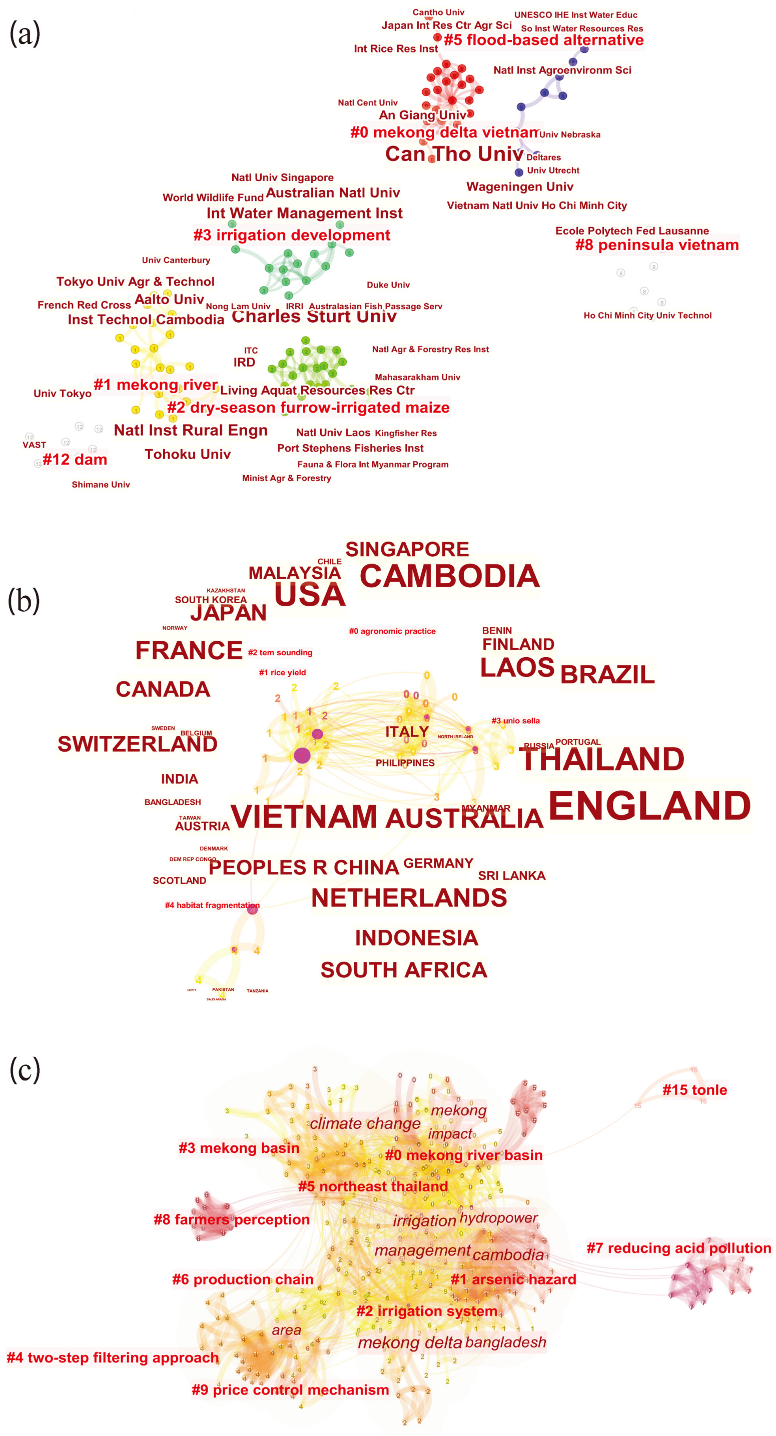

Figure 4. Bibliometric analysis results for cooperation network analysis: (**a**) institutions of authors; (**b**) countries of affiliated institutions; (**c**) co-citation analysis.

It gives a rough structure of the literature dataset generated using Citespace with the theme of institutions and countries of the authors. Citespace aggregates similar articles into a cluster with concentration, although the degree of concentration varies considerably between clusters. Each cluster generates a tag, which is assigned automatically by Citespace. The nodes in the figures are references cited by citing articles, and the distance between nodes represents the degree of association of keywords between articles. It is also reflected in the relative size of the different cluster tags. For example, "irrigation development" were studied by the National University of Singapore, the World Wildlife Fund, the Australian National University, and the International Water Management Institute. The labels of all nodes can be displayed in a picture. It is generally necessary to adjust the thresholds in the cluster to obtain a collaboration analysis graph that clearly illustrates the institutions. Some research themes deviate significantly from the clustered themes on the figure and, hence, are not displayed by the software.

Regarding the countries of authors' affiliations, Southeast Asian countries such as Vietnam, Laos and Cambodia have mainly focused on issues related to irrigation in the downstream areas. Research institutions in the United States, United Kingdom, Netherlands and China also made considerable contributions to those selected publications on LMB irrigation.

Figure 4c shows the co-citation results from the bibliometric analysis. Co-citation is used to determine the missing links between two relevant items using shared third items [55]. As mentioned above, each cluster has a label that represents the topic of the entire cluster. Figure 4c helps identify key literature for cross-disciplinary ideas. The label of clusters also shows a correlation between the articles that focus on Mekong irrigation issues, and environmental concerns, with a strong regional focus on the Mekong River Delta. Furthermore, there is a focus on issues between upstream hydropower development and irrigation of the LMB. Furthermore, climate change has a significant impact on the hydrological regimes in the Mekong River basin.

4. Thematic Analysis and Application of Remote Sensing

Figure 5 illustrates the matrix structure of the thematic analysis, which is organized based on initial analysis of the literature and on findings from the bibliometric review. According to modeling approaches, we categorized existing studies into land surface process modeling, systems modeling at river basin scale and reservoir operations. Considering irrigation, watershed management and hydropower as sub-systems in the LMB, land surface models nowadays incorporate irrigation module to analyze the effect of irrigation water withdrawal on downstream river flow; systems modeling at the river basin level, or river basin management modeling, address various complex issues related to water management in the basin; and reservoir operations modeling usually focuses on hydropower optimization and related downstream impacts. Within each sub-system, topics for review are organized into five aspects, including nature resources, socioeconomic, management, environment and infrastructure.

We selected several themes for further analysis, which are closely related to agricultural irrigation in the LMB: irrigation and crop production, water availability and land use, climate change and impact, environmental protection and soil and water conservation and integrated water resources management. Furthermore, remote sensing can be an effective tool for monitoring and managing irrigation in the Mekong region. Remote sensing can provide valuable insights into irrigation systems, crop growth and water availability in the Mekong region. By leveraging remote sensing technology, water authorities, farmers and policymakers can work together to create more sustainable and efficient irrigation systems that meet the needs of both people and the environment.

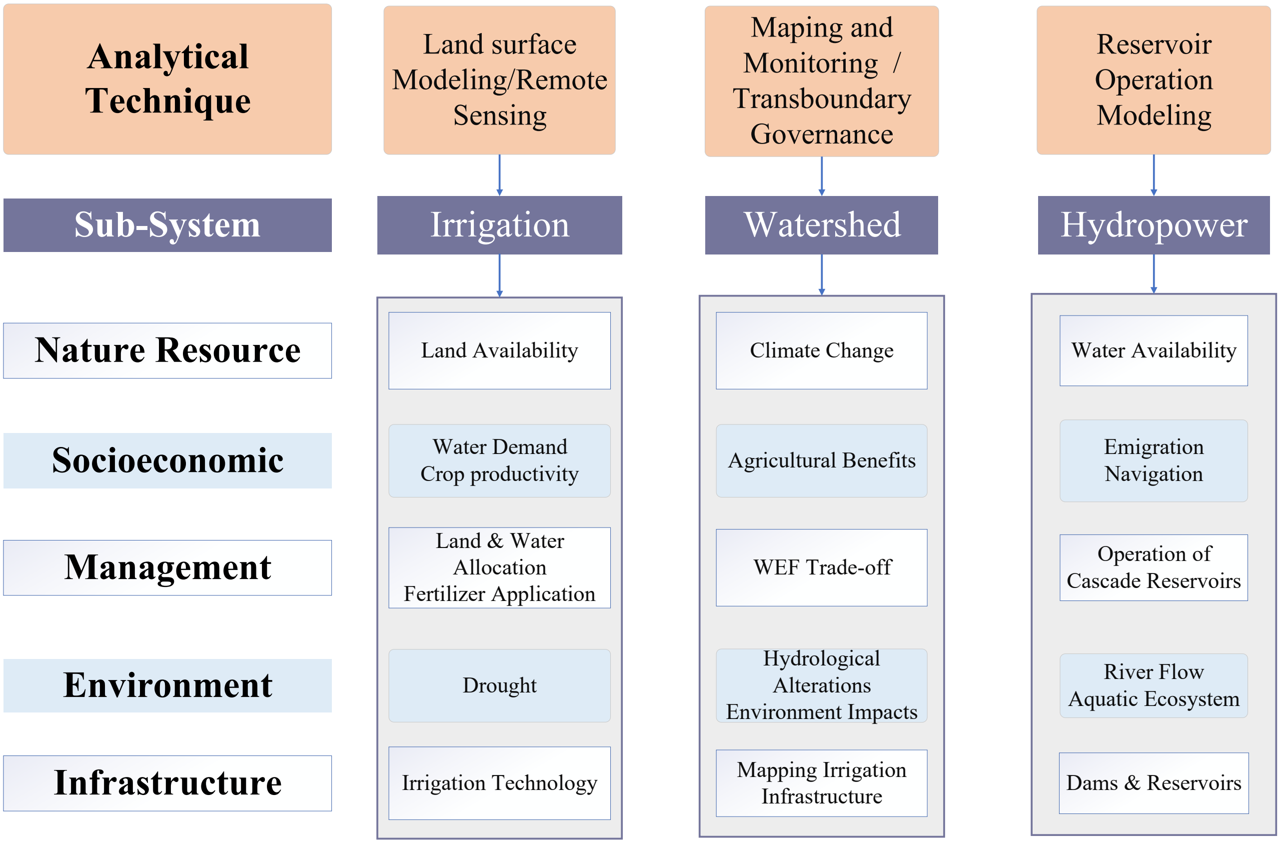

Figure 5. Organization of thematic review.

4.1. Irrigation and Crop Production

Irrigated crop production in the LMB plays an important role in regional economy. Moreover, Vietnam and Thailand are among the top rice exporters in the world. Thus, rice production in this region can have profound impacts on world rice prices. In the LMB, rice is the most important irrigated crop by irrigated crop area and by irrigation water consumption. Growing competition for water between irrigation and other economic sectors due to rapid population and economic growth poses a challenge to irrigation water management and requires close attention [56]. The Mekong River Basin features various hydraulic irrigation structures, such as dams, canals, weirs, pumping stations, embankments and water management systems. These structures play a crucial role in regulating water flow, distributing water for agriculture, managing floods and supporting crop cultivation. They contribute to enhanced agricultural productivity and livelihoods in the region.

Existing studies on irrigation estimated gridded irrigation water requirement in the LMB and other basins around the world [57]. For China, the impact of climate change was analyzed using the Community Land Model, version 4 [58]. Tatsumi et al. [59] conducted a detailed analysis of the impact of irrigation water abstraction on river flow using a simulation model to depict the changes in serval indicators within the LMB area. For the LMB, the CROPWAT model was also used for estimating irrigation water requirements [60]. In general, the literature suggests that more advanced irrigation technologies, appropriate crop varieties and enhanced agricultural extension are promising in improving irrigated agricultural production in the LMB.

In irrigation and crops, remote sensing can be used to map irrigation infrastructure, such as canals, reservoirs and water distribution systems. Landsat detected a significant decrease in the area of three types of rice crops as a way to judge the impact brought about [61]. This can help water authorities to identify areas where infrastructure upgrades or repairs are needed and to monitor changes in irrigation patterns and water use. Remote sensing has better applications in assessing water use and predicting crop water requirements. In crop health area, remote sensing can be used to assess crops health and to detect stress, disease or pest infestations [58]. This information can help farmers to take timely actions to mitigate crop losses and optimize water use and fertilizer application.

Remote sensing is a powerful technology that has found various applications in agriculture, with irrigation being a significant beneficiary. One of the critical aspects of effective irrigation management is determining the water requirements of crops, which is directly related to evapotranspiration (ET). Evapotranspiration is the combined process of water evaporation from the soil surface and transpiration from plant leaves. Remote sensing provides a non-intrusive and efficient method to monitor and estimate evapotranspiration over large agricultural areas. The process involves the use of satellite imagery, particularly the thermal infrared band and vegetation indices, to assess the temperature and health of crops. These data are integrated into surface energy balance models, which account for various factors affecting ET, such as solar radiation, sensible and latent heat fluxes.

4.2. Water Availability and Land Use

The country-wise water availability in the Mekong River Basin requires reassessment and a detailed description. The water availability in each country may fluctuate over time due to various factors, including changes in rainfall patterns, climate conditions, water usage and development projects such as dams and irrigation systems. A comprehensive reassessment would involve collecting and analyzing up-to-date data on water resources, including surface water and groundwater, in each country. It would also consider the impacts of existing and planned hydraulic structures, agricultural practices, industrial water usage and environmental considerations. There are significant variations in water availability in the Mekong region over time, including water levels in rivers, lakes and reservoirs. Water availability and land use are very important in the Mekong region, where water resources are scarce and unevenly distributed. Changes in land use patterns and flood conditions play an important role in the livelihood of local farmers, and remote sensing can be used to comprehensively monitor land use changes and flood conditions in the area and address the causes of land use changes [62].

Remote sensing information is used as a corresponding monitoring indicator to predict the timing and intensity of extreme events, including droughts and floods [63], as well as to allocate water resources more efficiently to manage them more effectively. Satellites are revolutionizing land use monitoring by providing unprecedented accuracy, resolution and coverage. Satellite-based land use monitoring has the capability to track land cover changes efficiently and effectively over a large range. This technology enables the detection of subtle changes in land use patterns [64], which can inform land management decisions and support sustainable development efforts. With its ability to capture frequent and consistent imagery, satellite-based land use monitoring has become an indispensable tool. Remote sensing can be used to identify areas that are currently being irrigated and to estimate the total area under irrigation. This information can be used to assess the overall water demand and to monitor changes in irrigation patterns over time.

4.3. Climate Change Impacts

Climate change is expected to affect the amount and timing of river flow in the LMB, and droughts and floods are likely to become more frequent [2]. On one hand, records already show that drought disaster is becoming more common in the region, resulting in reduced soil moisture, lower river flow and inadequate irrigation water supply [65–67]. On the other hand, floods may damage irrigation facilities, thereby restricting agricultural water use and even making irrigation impossible [68]. In addition, flood disasters can also cause water source pollution and water quality degradation, which have adverse effects on crop yield and quality [69]. Excessive soil moisture and high groundwater table also harm crop growth and increase the occurrence of pests and diseases of crops [70]. In this situation, the construction of flood prevention and drainage measures are essential. Faced with future climate-related stresses, crop profitability can be increased through water use efficiency, fertilizer management and crop management to improve the resilience of the local farming system [71].

Climate action is a crucial component in achieving the United Nations' Sustainable Development Goals, particularly in the context of sustainable irrigation practices. With the increasing impact of climate change on global water resources, it becomes imperative to implement effective measures that address both irrigation needs and environmental concerns. By embracing sustainable irrigation methods, we can address the challenges posed by climate change while striving for a more sustainable and food-secure future. Through collaborative efforts between governments, stakeholders and communities, we can pave the way for a resilient and environmentally conscious approach to agriculture and water management.

Climate change impacts irrigation: rising temperatures, erratic weather, prolonged droughts and extreme events disrupt irrigation schedules and reduce water availability. Melting glaciers and reduced snowpack diminish natural water supply, while increased evapotranspiration intensifies water demand. Floods and storms damage irrigation infrastructure. Solutions include adopting innovative technologies like remote sensing and precision irrigation, implementing water-use efficiency incentives and promoting sustainable water management practices. Collaboration is crucial to secure food production and conserve water resources for the future.

Surface temperature monitoring using remote sensing is one of the key variables in climate forecasting and climate change research, and therefore, the analysis of its behavior is essential to assess climate variability. Remote sensing technology can be used to increase people's understanding of the overall climate system and its changing laws. It can continuously observe and analyze the earth's surface, ocean and atmosphere at different time and space scales, so as to observe the climate system and investigate climate-related processes or long-term and short-term phenomena [72,73].

4.4. Environment Impacts

Groundwater overdraft for irrigation causes land subsidence, which is a serious problem in the Mekong River Delta [74]. Sea water intrusion becomes more serious with land subsidence, sometimes making groundwater unusable [75,76]. In the Mekong Delta, salinity intrusion has a direct impact on agriculture and domestic water uses [75].

The development of irrigation systems has a direct impact on local aquatic resources [77], adversely affecting aquatic fauna, especially fish [78–81]. The shrinkage of the Tonle Sap Lake has been attributed to climate change [82–86]. The reduction in rainfall in the Mekong Basin area has led to a decline in runoff from the Mekong [84], and the flow regime of the Tonle Sap has been influenced by the Mekong's hydrological fluctuation and irrigation water alternations. The environmental changes that are taking place in the Mekong region are manifested in terms of land use and land cover types. The causes of this change are various, including river damming, an increase in agricultural land and frequent natural disasters [87]. In arid and semi-arid regions of the world where water resources are scarce, agricultural issues are also the focus of local water crises [88].

Remote sensing data can be used to evaluate the environmental changes of large-scale river systems in the study of land cover changes in Mekong River Basin and their impacts on rivers [89]. The establishment of eco-environmental status indicators relies heavily on remote sensing technology, which is of great significance to the monitoring and analysis of ecosystems and environment on a large scale or even on a global scale. Wu et al. studied the use of remote sensing technology to point out natural and human pressures, regional natural environmental conditions, ecosystem health, land cover changes and responses to pressures [90].

4.5. Comprehensive Water Resource Management

4.5.1. Rational Water Allocation

The overarching goal of water resources management in the Mekong region is to enable the maximization of water-using benefits through equitable and efficient water allocation across all countries, water-using sectors and stakeholders [91]. Given the complexity of water management in the region, negotiation is desirable and necessary in solving conflicts in water allocation and management [92]. Modeling techniques in this area can be used to estimate the gains and losses under different cooperation arrangements. For instance, the Water Management Group from HR Wallingford seeks to recognize Pareto-optimal water allocation solutions across various users [93]. Trade-off analysis is a persuasive tool to tackle interdependence and complexity. Elsewhere, the mixed-integer linear programming method was used to obtain maximum irrigation net benefits [94]. Further studies using mathematical models are desirable to look into the complex challenges raised by different patterns of cooperation, damming schemes and water requirements of riparian countries [95–98]. Remote sensing can be used to optimize irrigation scheduling by monitoring water use and crop water stress. This information can help farmers to avoid over- or under-irrigation, which can lead to water wastage or crop stress.

4.5.2. Transboundary Water Management

Effective irrigation practices in the Mekong River basin are essential to enhance agricultural productivity and mitigate the impacts of climate change on water availability. However, transboundary water management has become a complex issue due to the shared nature of the river among multiple countries.

To address these challenges, regional cooperation is crucial. Collaborative efforts between the Mekong River countries are necessary to develop a comprehensive and integrated approach to water management. This involves sharing data, coordinating water release from upstream dams and jointly planning for irrigation and hydropower development. By promoting dialogue and cooperation, the countries can work together to balance the water needs for irrigation, energy production and environmental sustainability.

Transboundary water management in the Mekong River requires sustained cooperation and commitment among the riparian countries to address the complex challenges posed by shared water resources effectively. Through effective management and collaborative efforts, the Mekong River basin can achieve a balance between economic development, water security and environmental conservation for the benefit of all involved nations and their people.

4.5.3. Reconciling Hydropower and Irrigation

Upstream reservoirs store and release river flow for power generation, while downstream agricultural production relies on water diverted from the river channel to irrigate crops. Hydropower does not really "consume" water; it relies on the hydraulic head created by the elevation difference between reservoir water level and tail water level, and flow running through the turbines. Thus, managing the competition for water uses between these two sectors is largely about reconciling the timing and magnitude of water release for hydropower generation and that of irrigation water withdrawal.

Hydropower development in the Mekong River basin has attracted wide attention regionally and globally [99] due to its potential impacts on local hydrological conditions, agricultural development and ecosystems. Such impacts are often uncertain, significant and sometimes irreversible [8]. For instance, studies found that the loss of fisheries due to dam construction in the basin may lead to significant additional land and water uses for food production in maintenance of food security in the region [100,101]. It is worth noting that upstream reservoir storage can augment downstream river flow during the dry season and in dry years, thus benefiting downstream irrigation. To explore effective transboundary water management strategies in the Mekong, based on a real case in the 2016 drought in the basin, Zhang et al. [102] analyzed upstream reservoir operation strategies that can effectively mitigate drought impacts in the downstream. In some cases, existing or emerging conflicts in transboundary water management may even provide a more productive and transformative way forward than purely cooperative arrangements [103]. Efforts must be made in all participating processes to reconcile competing and possibly conflicting interests [104].

Remote sensing can be used to assess the potential of hydropower resources by analyzing water flow rates and elevation changes. This information can be used to identify areas where hydropower potential is high and to plan hydropower development projects more effectively [105]. The safety of dams and other water infrastructures using remote sensing is vital. This includes structural health monitoring [106] and changes in water levels, detecting seepage or erosion and assessing the stability of the surrounding terrain.

4.5.4. WEF Nexus in the Mekong

A growing number of scholars refer to the social relationships and biophysical interflow linking water, food and energy networks as "nexus" to draw attention to important interactions and risks that have been overlooked [107–109]. Although interest in synergies and trade-offs in the provision of the water-energy-food nexus is growing rapidly, proposals and recommendations for technological interventions are increasing. However, it is unclear what value the adoption of a nexus perspective has in understanding public policy for water resource management [110]. Weitz [110] also pointed out that our understanding of the meaning of managing WEF relationships and the conditions under which it can or cannot work is still very limited, and more empirical research is warranted on this issue.

The broad scope of the topics of interest discussed above (i.e., hydropower generation, flow regime change and water supply for agriculture and ecosystems downstream) represent a complex water–energy–food nexus in the entire Mekong River Basin. The "water-energy-food" nexus was established primarily for increasing resource-using efficiency, reducing trade-offs, creating synergies and improving overall watershed management to enhance water, energy and food security. A systematic investigation of multisectoral and transboundary tradeoffs within this nexus can provide scientific guidance for the riparian countries to cooperate effectively.

The emergence of this interconnected relationship is related to the underlying drivers: the critical importance of water, energy and food for human survival and the need to ensure their security, as well as greater awareness of the social and economic risks posed by the increasing scarcity of natural resources [111]. The nexus approach may help to identify co-benefits and external costs at the international level associated with actions in different sectors. Studying transboundary river basin WEF coupling relationships from a historical perspective allows for a more rigorous institutional analysis of benefit sharing in different sectors.

Water is an active driving force in the WEF nexus, and together with food and energy, the three resources are indispensable for human society. Society and the economy are significantly impacted by the growing shortage of resources such as water. Therefore, water resource planning and management are decisive factors [111]. Existing WEF studies include the quantitative study of resource flow and the degree of dependence, evaluation of technical indicators and policies and quantitative study of the degree of performance of the entire system [112]. There are also review articles that illustrate the concept of WEF nexus [113–116], simulation tools [117,118] and nexus governance [110] or implementation [119].

The water–energy–food security nexus is particularly challenging in transboundary river basin management. The WEF nexus is found to be useful because more actors are recognizing the interdependence between water management and food and energy production. Through the dialogues at the World Environment Forum, many actors saw themselves as a reasonable and sectoral entry point in a compelling, new, multi-sectoral, interdisciplinary and cross-border discussion [120]. The concept of relationship has different manifestations according to the background, scale and geographic environment of the review [121].

In WEF nexus, remote sensing technology also plays an important role. Various remote sensing can be used to determine and analyze the technical feasibility of integrating urban agriculture, rainwater harvesting and photovoltaic systems [122]. Moreover, using the WEF framework based on GIS, stakeholders can also evaluate the utilization of resources to achieve sustainable productivity [123].

5. Conclusions

Enhanced awareness and understanding of water management in general and irrigation in the LMB are of great importance for cross-border cooperation on water resources management for achieving equitable, rational and sustainable water uses and for promoting sustainable economic prosperity and societal development in riparian areas. In this paper, we conducted a bibliometric analysis of irrigation in the LMB by tapping into a large volume of publications. Based on identified key thematic areas, we further synthesized key issues and findings from existing studies through a thematic review. The bibliometric analysis systematically summarized key statistics and features of the literature body concerning LMB irrigation, such as journals where those articles were published, authors' affiliations and countries of origin, and collaborator network. We found that LMB irrigation has drawn wide attention within and outside of the region, and the number of publications has been rapidly increasing in recent years. The thematic analysis is based on the results of bibliometric analysis, focusing on themes including irrigation management and crop production, transboundary water management, climate change, environmental impacts and comprehensive water resources management.

Remote sensing technology has played a great role in different fields of agricultural irrigation. This review of remote sensing applications in this paper is expected to advance socio-hydrological research and inform science-based management decisions and policy formulation for sustainable food-energy-water, livelihoods and ecosystem development in the Mekong region, providing a strong basis for decisions to promote sustainable ecological development in the Greater Mekong Subregion.

We advocate for heightened awareness and understanding of water management, specifically irrigation in the LMB. This will facilitate cross-border cooperation on water resources, promoting equitable and sustainable water usage and contributing to economic prosperity and societal development in riparian areas. It is strongly suggested to prioritize the adoption of remote sensing technology in agricultural irrigation for well-informed decision-making and sustainable development in the Mekong region. By incorporating research insights and fostering collaboration, we can ensure responsible water use amid evolving challenges, such as those posed by climate change impacts.

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References

1. World Bank Group. *World Bank Mekong Vision 3.0, Supporting Riparian Countries of the Mekong River Basin and Related Stakeholders to Align Their Development Goals and Natural Resources Management Activities More Closely towards Long-Term Sustainability in the Context of Emerging Chall*; World Bank: Washington, DC, USA, 2019; p. 8.
2. Yamauchi, K. Climate Change Impacts on Agriculture and Irrigation in the Lower Mekong Basin. *Paddy Water Environ.* **2014**, *12*, 227–240. [CrossRef]
3. Economic Dimension—State of the Basin Report 2018 Findings. Available online: https://www.mrcmekong.org/interactive-publications/state-of-the-basin-report-2018/economic-dimension.html (accessed on 1 March 2023).
4. Molle, F.; Foran, T.; Käkönen, M. Irrigation in the Lower Mekong Basin Countries: The Beginning of a New Era? In *Contested Waterscapes in the Mekong Region: Hydropower, Livelihoods and Governance*; Routledge: London, UK, 2012; pp. 165–194. ISBN 9781849770.
5. FAO. *Water for Sustainable Food and Agriculture*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2017.
6. Sagara, J. *Surface Water Resources Improving Climate Resilience, Mekong Delta River Basin Groups: Assessment of the Tonle Sap and Productivity, and Sustainability*; ADB Briefs: Mandaluyong, Philippines, 2021; p. 20.
7. Boretti, A. Implications on Food Production of the Changing Water Cycle in the Vietnamese Mekong Delta. *Glob. Ecol. Conserv.* **2020**, *22*, e00989. [CrossRef]
8. Pokhrel, Y.; Burbano, M.; Roush, J.; Kang, H.; Sridhar, V.; Hyndman, D.W. A Review of the Integrated Effects of Changing Climate, Land Use, and Dams on Mekong River Hydrology. *Water* **2018**, *10*, 266. [CrossRef]
9. Smajgl, A.; Ward, J. *The Water-Food-Energy Nexus in the Mekong Region*; Springer: New York, NY, USA, 2013; pp. 971–978.
10. Liu, J.; Chen, S.; Wang, H.; Chen, X. Calculation of Carbon Footprints for Water Diversion and Desalination Projects. *Energy Procedia* **2015**, *75*, 2483–2494. [CrossRef]
11. Vora, N.; Shah, A.; Bilec, M.M.; Khanna, V. Food–Energy–Water Nexus: Quantifying Embodied Energy and GHG Emissions from Irrigation through Virtual Water Transfers in Food Trade. *ACS Sustain. Chem. Eng.* **2017**, *5*, 2119–2128. [CrossRef]
12. Holger, H. Clean Energy Solutions Center Understanding the Nexus. Background Paper for the Bonn 2011 Conference: The Water, Energy and Food Security Nexus. In Proceedings of the Bonn 2011 Conference, Bonn, Germany, 5 September 2011.
13. Liu, W.; Yang, H.; Tang, Q.; Liu, X. Understanding the Water-Food-Energy Nexus for Supporting Sustainable Food Production and Conserving Hydropower Potential in China. *Front. Environ. Sci.* **2019**, *7*, 1–10. [CrossRef]
14. Zhong, S.; Zhu, Y.; Zhao, J.; Shen, L. A Collaborative Framework for Hydropower Development and Sustainable Livelihood of Farmers in the Lancang-Mekong River Basin: A Review with the Perspective of Energy-Water-Food Nexus. *Water* **2022**, *14*, 499. [CrossRef]
15. Piman, T.; Lennaerts, T.; Southalack, P. Assessment of Hydrological Changes in the Lower Mekong Basin from Basin-Wide Development Scenarios. *Hydrol. Process.* **2013**, *27*, 2115–2125. [CrossRef]
16. Dombrowsky, I.; Hensengerth, O. Governing the Water-Energy-Food Nexus Related to Hydropower on Shared Rivers—The Role of Regional Organizations. *Front. Environ. Sci.* **2018**, *6*, 153. [CrossRef]
17. Zhang, X.; Li, H.-Y.; Deng, Z.D.; Ringler, C.; Gao, Y.; Hejazi, M.I.; Leung, L.R. Impacts of Climate Change, Policy and Water-Energy-Food Nexus on Hydropower Development. *Renew. Energy* **2018**, *116*, 827–834. [CrossRef]
18. Sabo, J.L.; Ruhi, A.; Holtgrieve, G.W.; Elliott, V.; Arias, M.E.; Ngor, P.B.; Räsänen, T.A.; Nam, S. Designing River Flows to Improve Food Security Futures in the Lower Mekong Basin. *Science* **2017**, *358*, 6368. [CrossRef] [PubMed]
19. Hamidov, A.; Helming, K. Sustainability Considerations in Water-Energy-Food Nexus Research in Irrigated Agriculture. *Sustainability* **2020**, *12*, 6274. [CrossRef]
20. Gao, W.; Guo, H.-C. Nitrogen Research at Watershed Scale: A Bibliometric Analysis during 1959–2011. *Scientometrics* **2014**, *99*, 737–753. [CrossRef]
21. Chen, C. Predictive Effects of Structural Variation on Citation Counts. *J. Am. Soc. Inf. Sci. Technol.* **2012**, *63*, 431–449. [CrossRef]
22. Opejin, A.K.; Aggarwal, R.M.; White, D.D.; Jones, J.L.; Maciejewski, R.; Mascaro, G.; Sarjoughian, H.S. A Bibliometric Analysis of Food-Energy-Water Nexus Literature. *Sustainability* **2020**, *12*, 1112. [CrossRef]
23. Chen, X.; Zou, D.; Xie, H. A Decade of Learning Analytics: Structural Topic Modeling Based Bibliometric Analysis. *Educ. Inf. Technol.* **2022**, *27*, 10517–10561. [CrossRef]
24. Donthu, N.; Kumar, S.; Mukherjee, D.; Pandey, N.; Lim, W.M. How to Conduct a Bibliometric Analysis: An Overview and Guidelines. *J. Bus. Res.* **2021**, *133*, 285–296. [CrossRef]
25. Chen, C. Science Mapping: A Systematic Review of the Literature. *J. Data Inf. Sci.* **2017**, *2*, 1–40. [CrossRef]
26. Chen, C. CiteSpace II: Detecting and Visualizing Emerging Trends and Transient Patterns in Scientific Literature. *J. Am. Soc. Inf. Sci. Technol.* **2006**, *57*, 359–377. [CrossRef]
27. Chen, C. *CiteSpace: A Practical Guide for Mapping Scientific Literature*; Nova Publishers: New York, NY, USA, 2016; ISBN 978-1-5361-0280-2.
28. Liu, J.; Chen, D.; Mao, G.; Irannezhad, M.; Pokhrel, Y. Past and Future Changes in Climate and Water Resources in the Lancang–Mekong River Basin: Current Understanding and Future Research Directions. *Engineering* **2022**, *13*, 144–152. [CrossRef]

29. Yamaguchi, T.; Tuan, L.M.; Minamikawa, K.; Yokoyama, S. Assessment of the Relationship between Adoption of a Knowledge-Intensive Water-Saving Technique and Irrigation Conditions in the Mekong Delta of Vietnam. *Agric. Water Manag.* **2019**, *212*, 162–171. [CrossRef]
30. Do, P.; Tian, F.; Zhu, T.; Zohidov, B.; Ni, G.; Lu, H.; Liu, H. Exploring Synergies in the Water-Food-Energy Nexus by Using an Integrated Hydro-Economic Optimization Model for the Lancang-Mekong River Basin. *Sci. Total Environ.* **2020**, *728*, 137996. [CrossRef] [PubMed]
31. Hoang, L.P.; van Vliet, M.T.H.H.; Kummu, M.; Lauri, H.; Koponen, J.; Supit, I.; Leemans, R.; Kabat, P.; Ludwig, F. The Mekong's Future Flows under Multiple Drivers: How Climate Change, Hydropower Developments and Irrigation Expansions Drive Hydrological Changes. *Sci. Total Environ.* **2019**, *649*, 601–609. [CrossRef]
32. Wang, K.; Liu, J.; Xia, J.; Wang, Z.; Meng, Y.; Chen, H.; Mao, G.; Ye, B. Understanding the Impacts of Climate Change and Socio-Economic Development through Food-Energy-Water Nexus: A Case Study of Mekong River Delta. *Resour. Conserv. Recycl.* **2021**, *167*, 105390. [CrossRef]
33. Polizzotto, M.L.; Kocar, B.D.; Benner, S.G.; Sampson, M.; Fendorf, S. Near-Surface Wetland Sediments as a Source of Arsenic Release to Ground Water in Asia. *Nature* **2008**, *454*, 505–508. [CrossRef]
34. Charlet, L.; Polya, D.A. Arsenic in Shallow, Reducing Groundwaters in Southern Asia: An Environmental Health Disaster. *Elements* **2006**, *2*, 91–96. [CrossRef]
35. Sakamoto, T.; Van Nguyen, N.; Ohno, H.; Ishitsuka, N.; Yokozawa, M. Spatio-Temporal Distribution of Rice Phenology and Cropping Systems in the Mekong Delta with Special Reference to the Seasonal Water Flow of the Mekong and Bassac Rivers. *Remote Sens. Environ.* **2006**, *100*, 1–16. [CrossRef]
36. Haddeland, I.; Lettenmaier, D.P.; Skaugen, T. Effects of Irrigation on the Water and Energy Balances of the Colorado and Mekong River Basins. *J. Hydrol.* **2006**, *324*, 210–223. [CrossRef]
37. Son, N.T.; Chen, C.F.; Chen, C.R.; Chang, L.Y.; Minh, V.Q. Monitoring Agricultural Drought in the Lower Mekong Basin Using MODIS NDVI and Land Surface Temperature Data. *Int. J. Appl. Earth Obs. Geoinf.* **2012**, *18*, 417–427. [CrossRef]
38. Sakamoto, T.; Wardlow, B.D.; Gitelson, A.A.; Verma, S.B.; Suyker, A.E.; Arkebauer, T.J. A Two-Step Filtering Approach for Detecting Maize and Soybean Phenology with Time-Series MODIS Data. *Remote Sens. Environ.* **2010**, *114*, 2146–2159. [CrossRef]
39. Polya, D.A.; Gault, A.G.; Diebe, N.; Feldman, P.; Rosenboom, J.W.; Gilligan, E.; Fredericks, D.; Milton, A.H.; Sampson, M.; Rowland, H.a.L.; et al. Arsenic Hazard in Shallow Cambodian Groundwaters. *Mineral. Mag.* **2005**, *69*, 807–823. [CrossRef]
40. Kummu, M.; Sarkkula, J. Impact of the Mekong River Flow Alteration on the Tonle Sap Flood Pulse. *Ambio* **2008**, *37*, 185–192. [CrossRef] [PubMed]
41. Kocar, B.D.; Polizzotto, M.L.; Benner, S.G.; Ying, S.C.; Ung, M.; Ouch, K.; Samreth, S.; Suy, B.; Phan, K.; Sampson, M.; et al. Integrated Biogeochemical and Hydrologic Processes Driving Arsenic Release from Shallow Sediments to Groundwaters of the Mekong Delta. *Appl. Geochem.* **2008**, *23*, 3059–3071. [CrossRef]
42. Su, F.; Zhang, L.; Ou, T.; Chen, D.; Yao, T.; Tong, K.; Qi, Y. Hydrological Response to Future Climate Changes for the Major Upstream River Basins in the Tibetan Plateau. *Glob. Planet. Chang.* **2016**, *136*, 82–95. [CrossRef]
43. Arias, M.E.; Cochrane, T.A.; Kummu, M.; Lauri, H.; Holtgrieve, G.W.; Koponen, J.; Piman, T. Impacts of Hydropower and Climate Change on Drivers of Ecological Productivity of Southeast Asia's Most Important Wetland. *Ecol. Model.* **2014**, *272*, 252–263. [CrossRef]
44. Hecht, J.S.; Lacombe, G.; Arias, M.E.; Dang, T.D.; Piman, T. Hydropower Dams of the Mekong River Basin: A Review of Their Hydrological Impacts. *J. Hydrol.* **2019**, *568*, 285–300. [CrossRef]
45. Dong, N.M.; Brandt, K.K.; Sørensen, J.; Hung, N.N.; Hach, C.V.; Tan, P.S.; Dalsgaard, T. Effects of Alternating Wetting and Drying versus Continuous Flooding on Fertilizer Nitrogen Fate in Rice Fields in the Mekong Delta, Vietnam. *Soil. Biol. Biochem.* **2021**, *47*, 166–174. [CrossRef]
46. Arias, M.E.; Cochrane, T.A.; Piman, T.; Kummu, M.; Caruso, B.S.; Killeen, T.J. Quantifying Changes in Flooding and Habitats in the Tonle Sap Lake (Cambodia) Caused by Water Infrastructure Development and Climate Change in the Mekong Basin. *J. Environ. Manag.* **2012**, *112*, 53–66. [CrossRef]
47. Son, N.-T.; Chen, C.-F.; Chen, C.-R.; Duc, H.-N.; Chang, L.-Y. A Phenology-Based Classification of Time-Series MODIS Data for Rice Crop Monitoring in Mekong Delta, Vietnam. *Remote Sens.* **2014**, *6*, 135–156. [CrossRef]
48. Biradar, C.M.; Xiao, X. Quantifying the Area and Spatial Distribution of Double- and Triple-Cropping Croplands in India with Multi-Temporal MODIS Imagery in 2005. *Int. J. Remote Sens.* **2011**, *32*, 367–386. [CrossRef]
49. Nguyen, T.T.H.; De Bie, C.A.J.M.; Ali, A.; Smaling, E.M.A.; Chu, T.H. Mapping the Irrigated Rice Cropping Patterns of the Mekong Delta, Vietnam, through Hyper-Temporal SPOT NDVI Image Analysis. *Int. J. Remote Sens.* **2012**, *33*, 415–434. [CrossRef]
50. Benner, S.G.; Polizzotto, M.L.; Kocar, B.D.; Ganguly, S.; Phan, K.; Ouch, K.; Sampson, M.; Fendorf, S. Groundwater Flow in an Arsenic-Contaminated Aquifer, Mekong Delta, Cambodia. *Appl. Geochem.* **2008**, *23*, 3072–3087. [CrossRef]
51. Wilbers, G.-J.; Becker, M.; Nga, L.T.; Sebesvari, Z.; Renaud, F.G. Spatial and Temporal Variability of Surface Water Pollution in the Mekong Delta, Vietnam. *Sci. Total Environ.* **2014**, *485*, 653–665. [CrossRef]
52. Sakamoto, T.; Van Phung, C.; Kotera, A.; Nguyen, K.D.; Yokozawa, M. Analysis of Rapid Expansion of Inland Aquaculture and Triple Rice-Cropping Areas in a Coastal Area of the Vietnamese Mekong Delta Using MODIS Time-Series Imagery. *Landsc. Urban. Plan.* **2009**, *92*, 34–46. [CrossRef]

53. Eto, M. Extended Co-Citation Search: Graph-Based Document Retrieval on a Co-Citation Network Containing Citation Context Information. *Inf. Process. Manag.* **2019**, *56*, 102046. [CrossRef]
54. Surwase, G.; Sagar, A.; Kademani, B.S.; Bhanumurthy, K. Co-Citation Analysis: An Overview. In *Beyond Librarianship: Creativity, Innovation and Discovery*; BOSLA: Mumbai, India, 2011.
55. Yun, J. Generalization of Bibliographic Coupling and Co-Citation Using the Node Split Network. *J. Informetr.* **2022**, *16*, 101291. [CrossRef]
56. Feng, J. Optimal Allocation of Regional Water Resources Based on Multi-Objective Dynamic Equilibrium Strategy. *Appl. Math. Model.* **2021**, *90*, 1183–1203. [CrossRef]
57. Döll, P.; Siebert, S. Global Modeling of Irrigation Water Requirements. *Water Resour. Res.* **2002**, *38*, 8–10. [CrossRef]
58. Leng, G.; Tang, Q. Modeling the Impacts of Future Climate Change on Irrigation over China: Sensitivity to Adjusted Projections. *J. Hydrometeorol.* **2014**, *15*, 2085–2103. [CrossRef]
59. Yamashiki, Y. Effect of Irrigation Water Withdrawals on Water and Energy Balance in the Mekong River Basin Using an Improved VIC Land Surface Model with Fewer Calibration Parameters. *Agric. Water Manag.* **2015**, *159*, 92–106. [CrossRef]
60. Le, A.T. Water Balance for Agriculture Production in the Dry Seasons of the Mekong River Delta in Vietnam. *Vietnam. J. Sci. Technol. Eng.* **2020**, *62*, 56–61. [CrossRef]
61. Hui, T.R.; Park, E.; Loc, H.H.; Tien, P.D. Long-Term Hydrological Alterations and the Agricultural Landscapes in the Mekong Delta: Insights from Remote Sensing and National Statistics. *Environ. Chall.* **2022**, *7*, 100454. [CrossRef]
62. Vu, H.T.D.; Tran, D.D.; Schenk, A.; Nguyen, C.P.; Vu, H.L.; Oberle, P.; Trinh, V.C.; Nestmann, F. Land Use Change in the Vietnamese Mekong Delta: New Evidence from Remote Sensing. *Sci. Total Environ.* **2022**, *813*, 151918. [CrossRef] [PubMed]
63. Mohammed, I.N.; Bolten, J.D.; Srinivasan, R.; Lakshmi, V. Satellite Observations and Modeling to Understand the Lower Mekong River Basin Streamflow Variability. *J. Hydrol.* **2018**, *564*, 559–573. [CrossRef]
64. Fonji, S.F.; Taff, G.N. Using Satellite Data to Monitor Land-Use Land-Cover Change in North-Eastern Latvia. *SpringerPlus* **2014**, *3*, 61. [CrossRef]
65. Kang, H.; Sridhar, V.; Mainuddin, M.; Trung, L.D. Future Rice Farming Threatened by Drought in the Lower Mekong Basin. *Sci. Rep.* **2021**, *11*, 9383. [CrossRef]
66. Zhang, L.; Song, W.; Song, W. Assessment of Agricultural Drought Risk in the Lancang-Mekong Region, South East Asia. *Int. J. Environ. Res. Public Health* **2020**, *17*, 6153. [CrossRef]
67. Zhang, B.; Zhang, L.; Guo, H.; Leinenkugel, P.; Zhou, Y.; Li, L.; Shen, Q. Drought Impact on Vegetation Productivity in the Lower Mekong Basin. *Int. J. Remote Sens.* **2014**, *35*, 2835–2856. [CrossRef]
68. Chen, X.; Liu, H.; Baiyinbaoligao; Mu, X. Summary of Flood and Drought in Mekong River Basin. In *Flood Prevention and Drought Relief in Mekong River Basin*; Liu, H., Ed.; Springer Tracts in Civil Engineering; Springer: Cham, Switzerland, 2020; pp. 27–54. ISBN 9789811520068.
69. Tilleard, S.; Turral, H.; Ketelsen, T.; Whiting, L. Climate Change, Water Scarcity and Agriculture: Lessons from the Countries of the Lower Mekong. In *Climate Risks to Water Security: Framing Effective Response in Asia and the Pacific*; Ojha, H., Schofield, N., Camkin, J., Eds.; Palgrave Studies in Climate Resilient Societies; Springer International Publishing: Cham, Switzerland, 2023; pp. 215–238. ISBN 978-3-031-16648-8.
70. Adeola, O.M.; Ramoelo, A.; Mantlana, B.; Mokotedi, O.; Silwana, W.; Tsele, P. Review of Publications on the Water-Energy-Food Nexus and Climate Change Adaptation Using Bibliometric Analysis: A Case Study of Africa. *Sustainability* **2022**, *14*, 13672. [CrossRef]
71. Nhẫn, P.P.; Hòa, L.V.; Quí, C.N.; Huy, N.X.; Hữu, T.P.; Macdonald, B.C.T.; Tường, T.P. Increasing Profitability and Water Use Efficiency of Triple Rice Crop Production in the Mekong Delta, Vietnam. *J. Agric. Sci.* **2016**, *154*, 1015–1025. [CrossRef]
72. Wang, X. Remote Sensing Applications to Climate Change. *Remote Sens.* **2023**, *15*, 747. [CrossRef]
73. Yang, J.; Gong, P.; Fu, R.; Zhang, M.; Chen, J.; Liang, S.; Xu, B.; Shi, J.; Dickinson, R. The Role of Satellite Remote Sensing in Climate Change Studies. *Nat. Clim. Chang.* **2013**, *3*, 875–883. [CrossRef]
74. Galloway, D.L.; Erkens, G.; Kuniansky, E.L.; Rowland, J.C. Preface: Land Subsidence Processes. *Hydrogeol. J.* **2016**, *24*, 547–550. [CrossRef]
75. Toan, T.Q. 9-Climate Change and Sea Level Rise in the Mekong Delta: Flood, Tidal Inundation, Salinity Intrusion, and Irrigation Adaptation Methods. In *Coastal Disasters and Climate Change in Vietnam*; Thao, N.D., Takagi, H., Esteban, M., Eds.; Elsevier: Amsterdam, The Netherlands, 2014; pp. 199–218. ISBN 978-0-12-800007-6.
76. Khang, N.D.; Kotera, A.; Sakamoto, T.; Yokozawa, M. Sensitivity of Salinity Intrusion to Sea Level Rise and River Flow Change in Vietnamese Mekong Delta-Impacts on Availability of Irrigation Water for Rice Cropping. *J. Agric. Meteorol.* **2008**, *64*, 167–176. [CrossRef]
77. Nilsson, C.; Reidy, C.A.; Dynesius, M.; Revenga, C. Fragmentation and Flow Regulation of the World's Large River Systems. *Science* **2005**, *308*, 405–408. [CrossRef]
78. Anderson, D.; Moggridge, H.; Warren, P.; Shucksmith, J. The Impacts of 'Run-of-River' Hydropower on the Physical and Ecological Condition of Rivers. *Water Environ. J.* **2015**, *29*, 268–276. [CrossRef]
79. Benejam, L.; Saura-Mas, S.; Bardina, M.; Solà, C.; Munné, A.; García-Berthou, E. Ecological Impacts of Small Hydropower Plants on Headwater Stream Fish: From Individual to Community Effects. *Ecol. Freshw. Fish.* **2016**, *25*, 295–306. [CrossRef]

80. Mbaka, J.G.; Wanjiru Mwaniki, M. A Global Review of the Downstream Effects of Small Impoundments on Stream Habitat Conditions and Macroinvertebrates. *Environ. Rev.* **2015**, *23*, 257–262. [CrossRef]
81. Mueller, M.; Pander, J.; Geist, J. The Effects of Weirs on Structural Stream Habitat and Biological Communities. *J. Appl. Ecol.* **2011**, *48*, 1450–1461. [CrossRef]
82. Arias, M.E.; Cochrane, T.A. *Impacts of Hydrological Alterations to the Tonle Sap Ecosystem of the Mekong River Basin*; American Geophysical Union: Washington, DC, USA, 2013.
83. Cochrane, T.A.; Arias, M.E.; Piman, T. Historical Impact of Water Infrastructure on Water Levels of the Mekong River and the Tonle Sap System. *Hydrol. Earth Syst. Sci.* **2014**, *18*, 4529–4541. [CrossRef]
84. Frappart, F.; Biancamaria, S.; Normandin, C.; Blarel, F.; Bourrel, L.; Aumont, M.; Azemar, P.; Vu, P.-L.; Le Toan, T.; Lubac, B.; et al. Influence of Recent Climatic Events on the Surface Water Storage of the Tonle Sap Lake. *Sci. Total Environ.* **2018**, *636*, 1520–1533. [CrossRef] [PubMed]
85. Wang, Y.; Feng, L.; Liu, J.; Hou, X.; Chen, D. Changes of Inundation Area and Water Turbidity of Tonle Sap Lake: Responses to Climate Changes or Upstream Dam Construction? *Environ. Res. Lett.* **2020**, *15*, 0940a1. [CrossRef]
86. Chen, X.; Zheng, Y.; Xu, B.; Wang, L.; Han, F.; Zhang, C. Balancing Competing Interests in the Mekong River Basin via the Operation of Cascade Hydropower Reservoirs in China: Insights from System Modeling. *J. Clean. Prod.* **2020**, *254*, 119967. [CrossRef]
87. Tran, H.; Tran, T.; Kervyn, M. Dynamics of Land Cover/Land Use Changes in the Mekong Delta, 1973–2011: A Remote Sensing Analysis of the Tran Van Thoi District, Ca Mau Province, Vietnam. *Remote Sens.* **2015**, *7*, 2899–2925. [CrossRef]
88. Rosegrant, M.W.; Ringler, C.; Zhu, T. Water for Agriculture: Maintaining Food Security under Growing Scarcity. *Annu. Rev. Environ. Resour.* **2009**, *34*, 205–222. [CrossRef]
89. Evers, J.; Pathirana, A. Adaptation to Climate Change in the Mekong River Basin: Introduction to the Special Issue. *Clim. Change* **2018**, *149*, 1–11. [CrossRef]
90. Wu, J.; Wang, X.; Zhong, B.; Yang, A.; Jue, K.; Wu, J.; Zhang, L.; Xu, W.; Wu, S.; Zhang, N.; et al. Ecological Environment Assessment for Greater Mekong Subregion Based on Pressure-State-Response Framework by Remote Sensing. *Ecol. Indic.* **2020**, *117*, 106521. [CrossRef]
91. Yuan, L.; He, W.; Liao, Z.; Degefu, D.M.; An, M.; Zhang, Z.; Wu, X. Allocating Water in the Mekong River Basin during the Dry Season. *Water* **2019**, *11*, 400. [CrossRef]
92. Degefu, D.M.; He, W. Allocating Water under Bankruptcy Scenario. *Water Resour. Manag.* **2016**, *30*, 3949–3964. [CrossRef]
93. Hurford, A.P.; Harou, J.J. Balancing Ecosystem Services with Energy and Food Security—Assessing Trade-Offs from Reservoir Operation and Irrigation Investments in Kenya's Tana Basin. *Hydrol. Earth Syst. Sci.* **2014**, *18*, 3259–3277. [CrossRef]
94. Tingsanchali, T.; Singh, P.R. Optimum Water Resources Allocation for Mekong-Chi-Mun Transbasin Irrigation Project, Northeast Thailand. *Water Int.* **1996**, *21*, 20–29. [CrossRef]
95. Johnston, R.; Kummu, M. Water Resource Models in the Mekong Basin: A Review. *Water Resour. Manag.* **2012**, *26*, 429–455. [CrossRef]
96. Ringler, C. ZEF Discussion Papers on Development Policy. In *Optimal Water Allocation in the Mekong River Basin*; ZEF Center for Development Research: Bonn, Germany, 2016; p. 41.
97. Wang, L.Z.; Fang, L.; Hipel, K.W. Water Resources Allocation: A Cooperative Game Theoretic Approach. *J. Environ. Inform.* **2003**, *2*, 11–22. [CrossRef]
98. Ziv, G.; Baran, E.; Nam, S.; Rodríguez-Iturbe, I.; Levin, S.A. Trading-off Fish Biodiversity, Food Security, and Hydropower in the Mekong River Basin. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 5609–5614. [CrossRef] [PubMed]
99. Ruida, Z.; Tongtiegang, Z.; Xiaohong, C. Evaluating the Tradeoff between Hydropower Benefit and Ecological Interest under Climate Change: How Will the Water-Energy-Ecosystem Nexus Evolve in the Upper Mekong Basin? *Energy* **2021**, *237*, 121518.
100. Stone, R. Dam-Building Threatens Mekong Fisheries. *Science* **2016**, *354*, 1084–1085. [CrossRef]
101. Orr, S.; Pittock, J.; Chapagain, A.; Dumaresq, D. Dams on the Mekong River: Lost Fish Protein and the Implications for Land and Water Resources. *Glob. Environ. Chang.* **2012**, *22*, 925–932. [CrossRef]
102. Yu, Y.; Zhao, J.; Li, D.; Wang, Z. Effects of Hydrologic Conditions and Reservoir Operation on Transboundary Cooperation in the Lancang–Mekong River Basin. *J. Water Resour. Plan. Manag.* **2019**, *145*, 04019020. [CrossRef]
103. Keskinen, M.; Salminen, E.; Haapala, J. Water Diplomacy Paths—An Approach to Recognise Water Diplomacy Actions in Shared Waters. *J. Hydrol.* **2021**, *602*, 126737. [CrossRef]
104. Middleton, C.; Devlaeminck, D.J. Reciprocity in Practice: The Hydropolitics of Equitable and Reasonable Utilization in the Lancang-Mekong Basin. *Int. Environ. Agreem. Politics Law. Econ.* **2021**, *21*, 235–253. [CrossRef]
105. Lin, Z.; Qi, J. A New Remote Sensing Approach to Enrich Hydropower Dams' Information and Assess Their Impact Distances: A Case Study in the Mekong River Basin. *Remote Sens.* **2019**, *11*, 3016. [CrossRef]
106. Zhu, Y.; Tang, H. Automatic Damage Detection and Diagnosis for Hydraulic Structures Using Drones and Artificial Intelligence Techniques. *Remote Sens.* **2023**, *15*, 615. [CrossRef]
107. Covarrubias, M. The Nexus between Water, Energy and Food in Cities: Towards Conceptualizing Socio-Material Interconnections. *Sustain. Sci.* **2019**, *14*, 277–287. [CrossRef]
108. Leck, H.; Conway, D.; Bradshaw, M.; Rees, J. Tracing the Water–Energy–Food Nexus: Description, Theory and Practice. *Geogr. Compass* **2015**, *9*, 445–460. [CrossRef]

109. Smajgl, A.; Ward, J.; Pluschke, L. The Water–Food–Energy Nexus–Realising a New Paradigm. *J. Hydrol.* **2016**, *533*, 533–540. [CrossRef]
110. Weitz, N.; Strambo, C.; Kemp-Benedict, E.; Nilsson, M. Closing the Governance Gaps in the Water-Energy-Food Nexus: Insights from Integrative Governance. *Glob. Environ. Chang.* **2017**, *45*, 165–173. [CrossRef]
111. Keskinen, M.; Varis, O. Water-Energy-Food Nexus in Large Asian River Basins. *Water* **2016**, *8*, 446. [CrossRef]
112. Chi, Z.; Xiaoxian, C.; Yu, L.; Wei, D.; Guangtao, F. Water-Energy-Food Nexus: Concepts, Questions and Methodologies. *J. Clean. Prod.* **2021**, *2018*, 625–639. [CrossRef]
113. Biggs, E.M.; Bruce, E.; Boruff, B.; Duncan, J.M.A.; Horsley, J.; Pauli, N.; McNeill, K.; Neef, A.; Van Ogtrop, F.; Curnow, J.; et al. Sustainable Development and the Water–Energy–Food Nexus: A Perspective on Livelihoods. *Environ. Sci. Policy* **2015**, *54*, 389–397. [CrossRef]
114. Cai, X.; Wallington, K.; Shafiee-Jood, M.; Marston, L. Understanding and Managing the Food-Energy-Water Nexus—Opportunities for Water Resources Research. *Adv. Water Resour.* **2018**, *111*, 259–273. [CrossRef]
115. De Grenade, R.; House-Peters, L.; Scott, C.A.; Thapa, B.; Mills-Novoa, M.; Gerlak, A.; Verbist, K. The Nexus: Reconsidering Environmental Security and Adaptive Capacity. *Curr. Opin. Environ. Sustain.* **2016**, *21*, 15–21. [CrossRef]
116. Wichelns, D. The Water-Energy-Food Nexus: Is the Increasing Attention Warranted, from Either a Research or Policy Perspective? *Environ. Sci. Policy* **2017**, *69*, 113–123. [CrossRef]
117. Dai, J.; Wu, S.; Han, G.; Weinberg, J.; Xie, X.; Wu, X.; Song, X.; Jia, B.; Xue, W.; Yang, Q. Water-Energy Nexus: A Review of Methods and Tools for Macro-Assessment. *Appl. Energy* **2018**, *210*, 393–408. [CrossRef]
118. Kaddoura, S.; El Khatib, S. Review of Water-Energy-Food Nexus Tools to Improve the Nexus Modelling Approach for Integrated Policy Making. *Environ. Sci. Policy* **2017**, *77*, 114–121. [CrossRef]
119. Vakilifard, N.; Anda, M.; Bahri, P.A.; Ho, G. The Role of Water-Energy Nexus in Optimising Water Supply Systems—Review of Techniques and Approaches. *Renew. Sustain. Energy Rev.* **2018**, *82*, 1424–1432. [CrossRef]
120. Dore, J.; Lebel, L.; Molle, F. A Framework for Analysing Transboundary Water Governance Complexes, Illustrated in the Mekong Region. *J. Hydrol.* **2012**, *466–467*, 23–36. [CrossRef]
121. Matthews, N.; Motta, S. Chinese State-Owned Enterprise Investment in Mekong Hydropower: Political and Economic Drivers and Their Implications across the Water, Energy, Food Nexus. *Water* **2015**, *7*, 6269–6284. [CrossRef]
122. Zambrano-Prado, P.; Muñoz-Liesa, J.; Josa, A.; Rieradevall, J.; Alamús, R.; Gasso-Domingo, S.; Gabarrell, X. Assessment of the food-water-energy nexus suitability of rooftops. A methodological remote sensing approach in an urban Mediterranean area. *Sustain. Cities Soc.* **2021**, *75*, 103287. [CrossRef]
123. Azzam, A.; Samy, G.; Hagras, M.A.; ElKholy, R. Geographic Information Systems-Based Framework for Water–Energy–Food Nexus Assessments. *Ain Shams Eng. J.* **2023**, 102224. [CrossRef]