Towards Understanding and Sustaining Natural Resource Systems through the Systems Perspective: A Systematic Evaluation

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Received: 8 November 2020; Accepted: 19 November 2020; Published: 25 November 2020

Abstract: A bibliometric and network analysis was performed to explore global research publication trends and to investigate relevant policy recommendations in the field of sustainability of natural resources, system dynamics, and systems thinking, to solve water resources issues and enhance water resource management. Overall, 1674 academic research articles data were generated from the Web of Science and Scopus databases, from 1981 to 2019. The findings of this study revealed that system dynamics and systems thinking research has significantly increased over the last decade (from 40 to 250 articles). Countries such as the USA (20%), China (18%), the United Kingdom (5%), Canada, Iran, Australia, and India (4% each) have the most publications and strongest collaborative networks. Sterman (2000) and Forrester (1961) had the most co-cited research while Zhang X had the highest citations, respectively. Results also showed that system theory which includes systems thinking and system dynamics were the most used keywords. The Journal of Cleaner Production was found to have published the highest number of systems thinking and system dynamics related studies, perhaps due to scope relevance. Despite the exponential rise in natural resource sustainability research globally, the result of this study shows that developing countries especially in Africa have low numbers of research publications in the field. Thus, the result of this study serves as a signal for policymakers to increase attention on research publications that could enhance natural resource sustainability, particularly in less developed countries in Africa where the application of systems thinking to natural resource management is limited.

Keywords: systems thinking; system dynamics; agricultural sustainability; water management; natural resource management; bibliometric analysis

1. Introduction

Humanity is currently facing unprecedented sustainability challenges. An example of this is the increasing per capita consumption among relatively wealthy groups, aggravated by the use of environmentally malign technologies and flawed socio-political arrangements, which is causing rapid deterioration of our life-support systems [1], such as agriculture, food energy, and water systems. This is manifested by the dramatic increase in climate disruptions, ocean acidifications and
eutrophication, global toxification and pollution, the impoverishment of biodiversity, water shortages, escalating resource conflicts, persistent levels of hunger and malnutrition, growing threats of vast epidemics, and expanding gaps between the rich and the poor that we are now experiencing [1–3]. Many key global sustainability challenges and their associated drivers are closely linked [2,4], making it difficult to study them in isolation and proffer appropriate solutions. Moreover, essential features of most natural resource systems, such as nonlinear feedbacks, strategic interactions, individual and spatial heterogeneity, and varying time scales pose substantial challenges for analyzing them [5,6]. Amidst these challenges, it is estimated that the planet’s demand for food and feed crops will almost double by 2050 [7,8]. These are the major bottlenecks that need to be overcome to achieve the targets of the Sustainable Development Goals (SDGs), which emphasized time-bound goals for Prosperity, People, Planet, Peace, and Partnership — known as the five P’s [9–11]. World leaders adopted the SDGs as a blueprint in 2015 to address the global challenges and embrace economic growth, social inclusion, and environmental protection [10].

Consequently, to address complex interconnections and identify effective solutions to sustainability challenges, the systems thinking approach is widely recognized as an approach that can offer a more useful perspective than other analytical approaches because the systems view is a way of thinking in terms of connectedness, relationships, and context [2,12–16]. The systems approach shares similar tenets with the concept of sustainability science, which has been widely drawn upon to explain how sustainability issues interrelate at both global and national levels [9,10,17,18]. Within the broader systems thinking framework, the system dynamics modeling approach [19–21] has also proven to be a novel tool to understand the structure and behavior of complex systems. These tools permit an adequate understanding of system implications of the sustainability of the complex human-environment system. Without this, there is a risk of unintended consequences of policies and technological innovations [5,6,22].

In general, the popularity of systems thinking and associated tools are based on the growing recognition that the conventional linear or reductionist methodologies are inadequate for solving complex sustainability problems [2,6]. Consequently, the volume of research and papers using systems thinking and system dynamics to understanding the sustainability of natural resource systems in recent years has increased exponentially. Applications in agriculture, food, energy, and water systems have been documented recently in the literature [23–25].

On the one hand, the growing number of studies presents research gaps and opportunities for new research. On the other hand, the research community often struggles to process the volume of information in the current competitive world. Therefore, it is of fundamental importance to identify, organize, and summarize the literature, discuss, and indicate possible trends. However, to our knowledge, no research has been carried out attempting to systematically review the literature and map the current state of scientific knowledge concerning the application of systems thinking and its related analytical tools, such as system dynamics in the context of agriculture, food, energy, and water systems. Bibliometric or scientometric analysis [26–28] provides an avenue to explore this.

Therefore, this paper used bibliometric and network analysis to quantitatively review the body of literature related to the application of systems thinking and system dynamics in studying the sustainability of the agriculture, energy, food, and water systems. Network analysis through bibliometric tools provided a powerful tool for identifying emerging areas of research and clusters that display similar attributes [29–32]. Specific attributes evaluated in this paper included a general perspective on the issue, publication patterns, most eminent authors and their respective clusters, journals with the highest citation per article, institutions with the highest citation per document, and countries with the highest productivity. The information presented in this paper provides a clear picture of the research progress achieved in the domain and could be useful for researchers and practitioners who have contributed to scientific production to identify other partners with common objectives with whom they could create links to work collaboratively and advance this important area that will continue to increase in importance.
2. Conceptual Understandings

2.1. Bibliometric Analysis Approach

The word ‘bibliometric’ has been derived from the Latin and Greek words ‘Biblio’ and ‘metrics’, respectively, which refer to the application of mathematics to the study of bibliography [28]. The approach has become one of the core domains of research in the broader field of library and information science. It relies on quantitative analysis and statistics to analyze patterns of publications within a given field or body of literature [28,33]. Bibliometric analysis is useful because it is a tool for searching and compiling a wide range of scientific articles from different disciplines and subjects from scientific databases, such as Web of Science (WoS) and Scopus based on the interest of the researcher [34]. An overview of the early approaches is provided by [27,35].

These techniques can assist researchers to identify “research gaps in different research disciplines, research patterns, influential authors and publications, leading journals, and other vibrant information in a research area [25]. Further, the technique enables scientific research carried out by researchers, institutions, regions, and countries to be analyzed and relevant trends in research to be identified [36–38]. One particular tool in this context is BibExcel, which is the most frequently used tool for bibliometric analysis because it is very flexible and allows for the modification and adjustment of data imported from different databases such as Scopus and Web of Science [29,38]. BibExcel uses a variety of network analysis tools such as Gephi, VOSviewer, and Pajek to perform comprehensive data analysis in various areas of research [39,40]. BibExcel was preferred in this study given the many advantages associated with it.

2.2. Systems Thinking and System Dynamics Approach

Ludwig von Bertalanffy is credited for proposing and developing what is now known as the General System Theory (GST) in 1969. In general, GST was based on the assumption that “a system is characterized by the interactions of its components and the nonlinearity of those interactions” [41]. This theory was proposed in support of the theory that a system could be broken into several components and each component analyzed as a separate entity, and the individual components could be added as a linear function to describe a complex system [42]. Systems thinking has become very popular for understanding complex systems because it provides a ‘new way of thinking’ to understand and manage complex problems at national and international scales [43–46]. Furthermore, as stated by Sterman [21], it helps us understand that “you can’t just do one thing and that everything is connected to everything else”. A complex system is driven by multiple drivers that are interrelated and interdependent [47,48].

A systems thinking (ST) approach is one of the most utilized problem-solving approaches or tools to address a wide range of problems affecting the system [12–14,49,50]. Systems thinking is increasingly becoming popular as a method of understanding and managing complex problems, whether they rest within a local context, or are globally experienced [43,44,51]. Causal Loops Diagrams (CLDs), system archetypes, stock and flow diagrams, tree diagrams, fuzzy cognitive maps, and rich pictures are ST tools that have been used to understand and gain valuable insights into sustainable development problems [1,52,53].

The system dynamics (SD) methodology was developed almost half a century ago as a framework to model the interactions of drivers and their influence on the functioning of a complex system with the main aim of improving the understanding of the causal relationships that interact to determine the dynamic behavior of a complex system [19]. Models based on a SD approach are considered a crucial means by which the dynamics of a problem may be simulated and from which an understanding could be generated into policies to improve system behavior [20]. System dynamics is one of the most popular systems thinking tools used for gaining a deeper understanding of complex system behaviors [21]. SD uses systemic feedback to simulate and gain insights into the complex behavior of the system ([53,54]. SD equally examines the causal-relationships that exist between key drivers
System dynamics modeling is a useful tool for simulating complex system problems through the structural identification of feedback structures that determine the behavior of the system [21,56]. SD is a powerful modeling technique for “framing, understanding and discussing complex issues and problems” [57].

System dynamics through qualitative and quantitative models identify relevant feedback and causal loops that govern the behavior and structure of a complex system [53,58,59]. The application and development of SD models have increased in demand since they provide a set of conceptual and mathematical tools that enable the understanding of the structure and dynamics of complex systems [20,21]. SD models through simulation and optimization design robust information feedback structures and control policies for managing the complex system [20,60]. SD is made up of two generic structures; the causal loop diagrams (CLDs) (qualitative modeling) and the stock and flow diagrams (quantitative modeling) [20]. These models have successfully been applied to various disciplines including natural resource management [61,62], energy consumption [59,63,64], agricultural development [55,65], food security [66,67] water resource management [17,23,68–70], and the water, energy, and food nexus (WEF) [24,53,71]. SD models have been applied to several fields and disciplines beyond those listed in this study but for the context of this study, only the areas listed will be considered. This is informed by the fact the SD models can integrate multiple dimensions of sustainability [5,72].

The uniqueness of the SD model is centered on its diversification to perform qualitative and quantitative modeling that allows for dynamic factor interaction and solving multiple systematic problems [14,55,73,74]. One of the tools used in the SD model is CLDs. CLDs are an important tool for representing the feedback structure of systems [21]. A CLD consists of variables connected by arrows denoting the causal relationships among the variables and are related by causal links, shown by arrows [21]. Each causal link is assigned a polarity, either positive (+) or negative (−) to indicate how the dependent variable changes when the independent variable changes. The important loops are highlighted by a loop identifier, which shows whether the loop is a positive (reinforcing) or negative (balancing) feedback [21,75–77]. Real-world data (historical data) can be used to simulate the dynamic interactions in the CLDs by building stocks and flows models [78]. Stocks and flows introduced by Forrester [19] used the flow of water into and out of reservoirs to describe the concept. According to Sterman [21], it is “helpful to think of stocks as bathtubs of water”. Understanding the dynamic behavior of a complex system is possible through modeling the accumulation or discharge within a stock [55].

3. Material and Methods

3.1. Data Retrieval

A multi-stage approach was used to achieve the objective of this study. Following the method used by [25], a structured literature review was performed first by defining relevant keywords, then performing a review of the literature, and analyzing the result. The method used in this study followed a step-by-step systematic approach starting from in-depth literature research using relevant keys words to develop the bibliography which makes it easier for the research gap to be identified. This study used published studies on natural resource sustainability and ST tools, obtained from the Web of Science (WOS) and Scopus databases on 16 June 2020. Scopus and WoS databases were selected in this study because together they provide the largest databases of peer-reviewed articles. Data was collected for these databases using selected keywords such as “sustainability analysis”, “natural resource sustainability”, “energy consumption”, “water resource management”, “agricultural sustainability”, “big-picture thinking”, “systems thinking”, “complex systems”, “system dynamics”, and “system theory” as the search terms in the title of the articles published between January 1981 and December 2019. Using specific keywords and titles when searching
The data generated from the search were analyzed using RStudio v3.4.1 software with bibliometrix R-package for bibliometric factors and network analysis. The analysis followed the procedures of Ekundayo and Okoh [81] and Orimoloye and Ololade [31,82] relating to data import into RStudio and translation into a bibliographic data frame, then structured for duplication (articles duplicated were limited to one record). For visualization, authors’ names, authors’ keywords, and keyword plus were generated. The spelling errors, variant names, and associations were reviewed in each collection in the analysis. For keywords, the co-occurrence of keyword and keyword-plus phrases were evaluated as a collection built into two categories. The prominent themes and the category-based test was performed for the keywords or a related keyword in an article that contributed to the natural resource management, sustainable water resources, agricultural sustainability, energy consumption, and water systems studies. The annual research on natural resource management and systems thinking was evaluated from 1981 to 2019, as shown in Figure 1.
The research on the sustainability of natural resources, system dynamics, and systems thinking published studies between 1981 and 2019 were evaluated in this study to identify the publication trend, influential authors, co-citation network, and collaboration network. The information in Figure 1 presents the annual publication frequency from 1981 to 2019; the result revealed that the number of publications in top journals has increased exponentially during the survey period especially between 2010 to 2019. This exponential increase in research publications could be explained by the fact that systems thinking tools and system dynamics were initially applied to economics and management sciences with little focus on natural resources management. The last decade has seen a rapid increase in the use of systems thinking tools in sustainability studies, especially the sustainability of natural resources. Hossain et al. [25] explained that the reason for this increase in systems thinking research could be that practitioners, academia, and industry have recognized the necessity of using systems thinking as a new way of thinking to deal with modern complex problems. Systems thinking tools and especially system dynamics have not been extensively applied to natural resource management yet, thereby leaving plenty of room for improvement and development in these areas [83]. Climate change, population growth, land degradation among other drivers are increasing the complexity of natural resources management [84]. The effects of these drivers are expected to grow continuously in the coming decades due to continuous anthropogenic activities [53]. This calls for an increase in the use of systems thinking tools to ensure the sustainability of natural resources [23]. For this reason, systems thinking tools are needed to understand and solve these problems, thereby increasing the use of systems thinking tools. The total number of publications increased from 2 publications in 1981 to 60 in 2010 and 238 publications in 2019 (Figure 1). This significant growth in the use of ST tools in natural resource sustainability publications shows the increasing popularity of systems thinking tools for solving complex problems related to natural resource management and it has not been used to full capacity. Following the current trend, it is expected that the usage of systems thinking tools will continue to gain more attention within natural resource management. This growth according to Hossain et al. [25] indicates clearly that systems thinking is receiving increasing attention in recent years, and the full-spectrum maturation of this domain is underway.

A citation analysis was performed to measure the citation frequency of research published from 1981 to 2019. Citation analysis reveals the number of times that a particular research has been cited in other research papers. Research papers with more citations are considered significantly more influential than articles with fewer citations [85,86]. Table 2 shows the top 10 influential sustainability research published between 1981 and 2019. It is important to note that the citation analysis performed
in this study is the most frequently used approach for literature analysis and it is very reliable [25,87]. The analysis performed revealed the most influential author, journal, DOI, and citation scores.

From the results in Table 2, Feng et al. [88] is the most cited research published in Ecological Modelling (Elsevier) with a total citation score of 223 and a citation score per year of 28 on average. This study extended the application of the system dynamics approach to model energy consumption in China. The study of Feng et al. [88] is a good example that demonstrates how systems thinking tools especially system dynamics can be applied to solving problems in natural resource management. Given the high citation score, the study represents a good reference point for research on natural resource management using systems thinking tools. The second most influential research is Zhang’s article, which has a total citation score of 141 citations and an average citation score of 7 citations per year. Synthesis of System Dynamics Tools for Holistic Conceptualization of Water Resources Problems by Mirchi [54] is the third most influential article with an average citation score of 123 citations and an average citation score of 15 citations per year.

The studies featured in Table 2 show the extent to which systems thinking tools and system dynamics have been applied to different areas of natural resource management ranging from energy management, climate change, agricultural sustainability, and water resource management. The list of most influential publications presented in Table 2 shows that there is a global interest in the application of systems thinking and system dynamics in natural resources management. Given the exponential rise in the use of ST tools globally, it is important to examine the contribution of countries in terms of single and multiple country publications.

Figure 2 shows the top 10 countries in the domain of systems thinking and system dynamics in terms of single and multiple country publications. In terms of single and multiple country publications, the result shows that the USA has the largest single country publication level (20%), followed by China (18%), the United Kingdom (UK) (5%), and Canada, Iran, and Australia, (4% each). Furthermore, India, Germany, Japan, the Netherlands (2%), and Spain had the lowest single country publication levels of approximately 1% during the survey period. The findings of this study correlate with the findings of Hossain et al. [25] who found that the USA, UK, Australia, and Canada represent countries with the most productive single country publication levels in systems thinking research globally. The recent decade has seen a significant rise in the use of systems thinking tools in natural resource management globally, while regional and global research partnerships have become an increasing trend over the years. Of the entire total multiple country publications, the United Kingdom (33%), Germany (25%), Canada (24%), Australia (23%), and China (20%) were ranked as the top five countries.
Table 2. Top 10 Author Production over Time Documents in Natural resource management using systems thinking (ST) tools research.

| Author  | Year | Title                                                                 | Sources                         | DOI                              | TC  | TCpY  |
|---------|------|----------------------------------------------------------------------|---------------------------------|---------------------------------|-----|-------|
| Feng Y. | 2013 | System dynamics modeling for urban energy consumption and CO₂ emissions: A case study of Beijing, China | Ecological Modelling             | 10.1016/J.ECOLMODEL.2012.09.008 | 223 | 27.875|
| Zhang X | 2002 | Sustainability analysis for Yellow River water resources using the system dynamics approach | Water Resources Management       | 10.1023/A:1020206826669         | 141 | 7.421 |
| Mirchi A | 2012 | Synthesis of system dynamics tools for holistic conceptualization of water resources problems | Water Resource Management        | 10.1007/s11269-012-0024-2        | 123 | 15.375|
| Simonovic | 2002 | System dynamics model for predicting floods from snowmelt in North American prairie watersheds | Hydrological Processes           | 10.1002/HYP.1064                 | 96  | 5.052 |
| Wang Y  | 2014 | Optimization of the irrigation water resources for agricultural sustainability in Tarim River Basin, China | Journal of Cleaner Production     | 10.1016/J.JCLEPRO.2014.03.023   | 88  | 12.571|
| Huang Y | 2012 | A system dynamics model for analyzing energy consumption and CO₂ emission in the Iranian cement industry under various production and export scenarios | Agricultural Water Management     | 10.1016/J.AGWAT.2012.01.012      | 81  | 9     |
| Ansari N. | 2013 | A system dynamics model for analyzing energy consumption and CO₂ emission in the Iranian cement industry under various production and export scenarios | Energy Policy                    | 10.1016/J.ENPOL.2013.02.042     | 50  | 5     |
| Liu J   | 2008 | System dynamics and hybrid particle swarm optimization for land use allocation | Ground Water                    | 10.1111/J.1745-6584.2008.00486X | 74  | 5.693 |
| Li X    | 2013 | Combining system dynamics and hybrid particle swarm optimization for land use allocation | Ecological Modelling             | 10.1016/J.ECOLMODEL.2013.02.027 | 65  | 8.125 |
| Zhang L | 2015 | How might China achieve its 2020 emissions target? A scenario analysis of energy consumption and CO₂ emissions using the system dynamics model | Journal of Cleaner Production     | 10.1016/J.JCLEPRO.2014.12.080   | 63  | 10.5  |
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The USA, China, the United Kingdom, Canada, Australia, Japan, and Spain are the countries that appear in both the top 10 countries in research production per country (Figure 2) and the top 10 countries in research production based on total citations (Figure 3). This means that these countries are producing research that is relevant to the sustainability of natural resource management and the publications are cited in the research community. However, countries like Germany, Iran, India, Italy, and the Netherlands appear in the top 10 countries in research production but are not in the top 10 countries for research production based on total citations. This development may be a result of non-interdisciplinary or regional-based research, which may not be applicable or cited by other researchers from other regions or fields, which might have affected their citation patterns.
Furthermore, the citation analysis explored the total citations of publications per country of research. The analysis estimated the number of citations by country and the average citations per article per country (Figure 3). The analysis estimated and compared publications for 10 countries around the world. Following the same pattern as total research publications by country (Figure 2), the results in Figure 3 show that the USA (n = 6628), China (n = 2745), United Kingdom (n = 1740), Canada (n = 1267), the Netherlands (n = 1224) and Australia (n = 1160) were the countries with the highest number of citations. Other countries with high article citations were Iran (n = 810), Switzerland (n = 806), Spain (n = 729) and Japan (n = 714). This list is dominated by developed countries showing a growing interest in the application of systems thinking tools in developed countries. However, China (2745) was the only developing country to feature in the top 10, with no African country making the top 10 list. The application of systems thinking tools to natural resource management is scarce in developing countries, especially in Africa. Having highlighted the benefits of systems thinking to planning and management of natural resources, developing countries are encouraged to utilize these tools for natural resource management.

Although in recent years some studies have been done in Africa using systems thinking tools to solve problems related to water resource management and agricultural sustainability [23,89,90], there is still a wide gap to be filled by researchers in the field of systems thinking, system dynamics and natural resource management in developing countries around the world especially in countries in Africa. The successful application of systems thinking tools to solve complex problems often requires the involvement of stakeholders and decision-makers. As a result, planning the process is often time-consuming and expensive to execute. This could explain the reason why very few studies are applying system-thinking tools to solve complex problems in developing countries who often lack the financial resources and collaborative ties to carry out large-scale research. Zhang et al. [91] and Orimoloye et al. [32] have suggested that research funding and scholarships have greatly influenced the research output of many nations. Therefore, this study suggests that financial support could aid the development of research in the field of systems thinking, system dynamics, and natural resource management.

Table 3 shows the distribution of outputs in the top journals on systems thinking research from 1981 to 2019. The rank of journals publishing the systems thinking research was analyzed based on the frequency of publication, the cumulative frequency of publication, publication per year, total citations, and the h-index indicator, as presented in Table 3. The h-index is a measure of research impact, as proposed by Hirsch [92].

The average total citations of publications fluctuated over the years of which among the journals, the Journal of Cleaner Production has the highest total citation of 1634, with an h-index of 20, as shown in Table 3. This journal also ranked first with a total number of publications per year of 65. Journal of Environmental Management was ranked the second journal with the most publications and citations in systems thinking and natural resource sustainability with a total citation of 1190 (h_index = 13), with 18 publications per year in this domain. The other top-rated journals in systems thinking and natural resource management have a total of 1173, 1055, 838, and 788 citations in articles published in Agriculture, Ecosystems, and Environment (h-index of 12), Water Resources Management (h-index of 13), Energy Policy (h-index of 18), and Ecological Modelling (h-index of 13) respectively. The top six journals selected based on citations and h-index published a high volume of application of systems thinking to natural resource management research between 1981 and 2017, which account for only 65% of all the total journal citations. Journals such as Energy, Agricultural Systems, Ecology and Society, Environmental Modelling and Software, Science of The Total Environment, and Sustainability (Switzerland), have substantial publications and citations in the domain, thereby making a significant contribution to the fields of systems thinking and natural resource management.
Table 3. Source Impact on systems thinking and natural resource management research.

| Source                                           | H_index | TC   | NP  | PY_start |
|--------------------------------------------------|---------|------|-----|----------|
| Journal of Cleaner Production                     | 20      | 1634 | 67  | 1999     |
| Sustainability (Switzerland)                      | 10      | 396  | 65  | 2014     |
| Energy Policy                                     | 18      | 838  | 29  | 1992     |
| Ecological Modelling                              | 13      | 788  | 22  | 1981     |
| IOP Conference Series: Earth and Environmental Science | 1      | 5    | 22  | 2017     |
| Energy                                           | 18      | 674  | 21  | 2007     |
| Plos ONE                                         | 7       | 162  | 21  | 2008     |
| Water Resources Management                        | 13      | 1055 | 21  | 2002     |
| Ecology and Society                               | 11      | 513  | 18  | 2008     |
| Journal of Environmental Management               | 13      | 1190 | 18  | 2001     |
| Sae Technical Papers                              | 3       | 42   | 18  | 1989     |
| Resources, Conservation and Recycling             | 12      | 480  | 17  | 2011     |
| Water (Switzerland)                               | 8       | 164  | 17  | 2010     |
| Agricultural Systems                              | 10      | 632  | 16  | 1984     |
| Agriculture, Ecosystems, and Environment           | 12      | 1173 | 16  | 1992     |
| Environmental Modelling and Software              | 9       | 425  | 15  | 1998     |
| Science of the Total Environment                  | 10      | 431  | 14  | 2012     |
| International Journal of Agricultural Sustainability | 7     | 254  | 13  | 2003     |
| Ecological Indicators                             | 8       | 295  | 12  | 2011     |
| Sustainability                                    | 9       | 250  | 11  | 2010     |

Figure 4 summarizes the top 50 most used keywords on natural resource management and systems thinking research. A word cloud was employed to identify the titles of published papers of the most commonly used terms in publications during the survey period. This established the predominant words or terms used in the published research. It is easy to differentiate within the word-cloud on publication and work out different areas of associations as well as identify the most central terms used during the period. For example, based on the frequency of occurrence, systems theory (n = 395), system dynamics (n = 317), sustainable development (n = 258), China (n = 200), water management (n = 195), sustainability (n = 193), decision making (n = 193), water supply (193), climate change (n = 153), system dynamic model (n = 145), computer simulation (n = 135), economics (n = 106), simulation (n = 103), and scenario analysis (n = 99) were identified as the most used or dominant terms in natural resource sustainability and systems thinking research. China is among the dominant terms in natural resource sustainability and systems thinking research, which indicates that the country has increased the application of systems thinking tool to solve complex problems related to water management [93], CO2 emissions, and energy management [88], and agricultural development [2] for example.

Co-citation network analysis examines the relationship between influential authors, trending topics, journals, and keywords [94]. Articles are considered to be co-cited if they are both cited and appear on the reference lists of other publications [25]. This analysis ensures that influential natural resource management and systems thinking publications and their evolution during the survey period are examined. The frequency and strength of the co-citation network of 20 authors and their publications are shown in Figure 5. The result shows that Sterman (2000) and Forrester (1961) are the top co-cited publications in systems thinking and system dynamics. The study by Sterman (2000) has been widely used by beginners and experts in systems thinking and dynamics research. The book is frequently used as a guide for systems thinking and system dynamics research. Industrial dynamics by Forrester (1961) provides great insights into modeling complex systems using system dynamics. These studies have gained prominence due to the increased use of systems thinking and system dynamics in literature. It is important to note that these publications introduced the concepts of a bathtub in modeling and simulations in system dynamics, the causal loop diagrams (CLDs), causal relationships, feedback, stocks and flows, time delays, and nonlinearity (Torres, 2019). These publications also have a strong co-citation network with Winz et al. [95], Forrester [19], Barlas [96], Stave [97].
Figure 4. Word Cloud of Top 50 emerging words in natural resource management and ST research (1981–2020).

Figure 5. Authors and documents in a co-citation network. Each colored node represents the author. Connected lines depict co-citation network frequency, while node diameter shows co-citation network strength.

The corresponding collaborative network diagram is presented in Figure 6, showing the strength and frequency of countries. Each colored node represents the country while the connected lines depict collaboration frequency, and the node diameter shows collaboration strength. The higher the lines, the stronger the collaborative network. The results show that the United Kingdom, China, USA, Canada, Netherlands, and Australia were ranked as the highest countries with strong collaborative ties.
(Figure 6). The results show very strong collaborative ties between the USA and China. This means that these countries are using their resources to collaborate and produce high-quality research on these topics. This could explain the reason why the USA and China are the top two countries in terms of articles produced and total citations.

![Collaboration networks for Countries](image_url)

Figure 6. Collaboration networks for Countries. Each colored node represents the author, institution, and country. Connected lines depict collaboration frequency, while node diameter shows collaboration strength.

5. Application of Systems Thinking to Policy Discourse

Systems thinking and its concomitant approaches have become popular because natural resource managers have started reflecting upon the practical implications of being holistic in their analysis of complex environmental systems [53]. In essence, “systems thinking tools provide are useful to serve the decision-makers’ needs to understand the functioning of complex systems, compare impacts among decision scenarios, analyze trade-offs among options, ask ‘What if?’ questions, avoid the creation or transfer of problems in pursuing solutions to the problem at hand, adapt strategies based on future monitoring of the system, and respond to unintended consequences” [98]. Due to a lack of understanding of the functioning of complex systems by policymakers, well-intentioned efforts to solve pressing problems often create unintended consequences, resulting in policy resistance and negative responses to interventions by the system to the intervention itself [78]. Systems thinking provides a framework for policymakers to understand the functioning of the complex system in order to develop practical and inclusive policies capable of avoiding policy resistance [99]. Systems thinking enables policy-makers to learn complex systems faster and more effectively, identify high leverage points, avoid policy resistance, and make decisions consistent with long-term best interests [50,100]. As a result, systems thinking has become an area of interest for government, researchers, scientists, and scholars in different fields, including engineering, business management, education, healthcare, natural resources among others. Systems thinking and its concomitant approaches have been applied to different fields with varying results. This study, however, examined the application of systems thinking to natural resource management. Some studies were chosen to demonstrate the application of systems thinking and concomitant approaches to different areas of natural resources management. This was to demonstrate the usefulness of the approach and how the application of systems thinking tools can provide solutions to complex natural resource management problems (Table 4). The findings and conclusions of these studies are centered on developing policies for sustaining natural resources.
Table 4. A list of systems thinking related studies, showing authors names, publication year, research approach, key results, and policy recommendations.

| S/N | Author(s) | Main Concepts | Major Findings | Recommendations |
|-----|-----------|---------------|----------------|----------------|
| 1.  | Mirchi et al. [54] | Used systems thinking and system dynamics as a method to facilitate a holistic understanding of water resources systems, and strategic decision-making. | This study provided an overview of Causal Loop and Stock and Flow Diagrams, reference modes of dynamic behavior, and system archetypes to demonstrate the use of these qualitative tools for a holistic conceptualization of water resources problems. | The study provided the benefits as well as caveats of qualitative system dynamics for water resources decision making. |
| 2.  | Inam et al. [68] | This study developed a systematic method to initialize the involvement of key stakeholders in the development of qualitative system dynamics models (i.e., causal loop diagrams) for soil salinity management in agricultural watersheds. The proposed approach is designed to overcome the challenges of low expertise, time, and financial resources that have hampered previous participatory modeling efforts in developing countries. | The case study demonstrates the usefulness of the proposed approach, based on using causal loop diagrams in initiating stakeholder involvement in the participatory model building process. | The participatory model developed in this can support decision-making in soil salinity management, considering stakeholder perceptions as well as social, environmental, and economic aspects of the problem. |
| 3.  | Kotir et al. [69] | Develop an integrated SD simulation model to examine the feedback processes and interaction between the population, the water resource, and the agricultural production sub-sectors of the Volta River Basin in West Africa. | Results of the business as usual scenario showed that the total population, agricultural, domestic, and industrial water demands would continue to increase over the simulated period. Besides business as usual, three additional policy scenarios were simulated to assess their impacts on water demands, crop yield, and net-farm income. These were the development of the water infrastructure (scenario 1), cropland expansion (scenario 2), and dry conditions (scenario 3) | Overall, the model results could help inform policymaking, planning, and investment decisions within the basin to enhance water and food security, livelihoods, economic development, socio-economic growth, and sustainable management of natural resources. |
| 4.  | Chapman & Darby, [65] | To develop and test a new SD model which simulates the dynamics between farmers’ economic system and their rice agriculture operations | The results suggest that the current dominant strategy (triple cropping) is only optimal for wealthier groups within society and over the short-term (ca. 10 years post-implementation). | The model suggests that the policy of opening sluice gates and leaving paddies fallow during high-flood years, in order to encourage natural sediment deposition and the nutrient replenishment it supplies, is both more equitable and more sustainable. |
Table 4. Cont.

| S/N | Author(s) | Main Concepts | Major Findings | Recommendations |
|-----|-----------|---------------|----------------|----------------|
| 5.  | Bahri, [101] | This paper applied system archetypes to investigate water, energy, food, and land nexus (WEFLN) in the Jatiluhur reservoir, the largest reservoir in Indonesia. | The study found that growth engines such as industrial development and residential development support industrial and residential sectors. However, water availability will be a crucial issue as water supply can bound the growth engines. | The results of this study can provide a policy tool for policymakers to monitor and apply limits to growth in order to sustain water resources. |

6. Conclusions

Systems thinking and system dynamics have gained interest and popularity among researchers, experts, and decision-makers in public and private sectors, and have been applied in diverse disciplines natural resource management, economics and management, public health, engineering, and education among others. However, despite the increase in the application of systems thinking tools to solve complex problems, most developing countries are yet to apply these tools for complex problem-solving. This study performed bibliometric and network analyses to explore global research publication trends and to investigate relevant policy recommendations in the field of sustainability of natural resources, system dynamics, and systems thinking, to solve water resources issues and enhance water resource management. Overall, data from 1674 academic research articles were generated from the Web of Science and Scopus databases, from 1981 to 2019. The findings of this study revealed that system dynamics and systems thinking research has significantly increased over the last decade (from 40 to 250 articles). Countries such as the USA (20%), China (18%), United Kingdom (5%), Canada, Iran, Australia, and India (4% each) have the most publications and the strongest collaborative networks. Sterman [21] and Forrester [19] had the most co-cited research while Zhang X had the highest citations, respectively. Results also show that system theory which includes systems thinking and system dynamics were the most used keywords. The journal of cleaner production was found to have published the highest number of systems thinking and system dynamics related studies, perhaps due to scope relevance. Despite the exponential rise in natural resource sustainability research globally, the result of this study shows that developing countries especially in Africa have low research publications in the field. Thus, the result of this study serves as a signal for policymakers to increase attention on research publications that could enhance natural resource sustainability particularly in less developed countries in Africa. Though the findings of this study have great potentials, there are some weaknesses related to the research design and the analytical approach. While the bibliometric approach has strengths, there are some weaknesses associated with the approach. The research analyzed data only from the WoS and Scopus databases and therefore might have limited scope of obtained results because the full range of natural resources and ST publications might not have been captured and analyzed. This is the first study that has attempted to analyze the application of systems thinking tools to natural resources management. This means that further studies can be carried out to explore all scientific databases to examine the full impact of natural resource sustainability and systems thinking research.

Author Contributions: This research was Conceptualized by Y.S.N., A.A.A., and I.R.O. I.R.O. did data collection and analysis (software analysis). Writing—original draft preparation was done by Y.S.N. and J.H.K., writing—A.A.A. did the review and editing of the manuscript; writing supervision was done by A.A.O., and the project funding acquisition was by A.J.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Water Research Commission, grant number (K5/2711/4) and “The APC was funded by Water Research Commission”.

Acknowledgments: This study is based on a project, ‘Agricultural water management scenarios for South Africa (K5/2711/4)’, which was initiated, managed, and funded by the Water Research Commission (WRC).
South Africa. Sincere appreciation goes to the Water Research Commission and the National Research Function (NRF) for financial and other contributions, and to other team members.

Conflicts of Interest: The authors declare no conflict of interest.

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