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Water-energy-food nexus as a new approach for watershed resources management: a review

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Abstract
The Water-Energy-Food nexus (WEF) has been initially introduced in the international community as an adaptive management approach in response to climate change. This study aims to review and analyze the existing literature on WEF nexus approach at different scales and to suggest supplementary ideas for better applicability of WEF nexus framework in integrated watershed management. In terms of geographical distribution, the study covers Asia (Central, South, Southeast, and East), Australia, Africa (North, South, and East), North America (USA, Mexico, and Canada), South America (Brazil), Europe (UK, Italy, Germany, Spain, Sweden, and Greece), and Oceania. For this, 203 articles and documents were found dealing with WEF nexus. Interest over time in WEF nexus was examined from 2011 to 2019 in these regions. The review showed 10 articles had a close linkage with water–food, 49 with water-energy, 119 with water-energy-food, six with water-food-energy-ecosystems, five with water-energy-land-food, three with food-energy-environment, three with water-soil-waste and eight with climate. We propose ecosystem services and other important commodities like soil be considered in future nexus relevant studies. Towards this, the soil-water-energy-food (SWEF) nexus is introduced as a useful approach towards higher sustainability and adaptive management at the watershed scale.

Keywords: Adaptive Management, Integrated Watershed Management, Soil-Water-Energy-Food Nexus, Trade-Offs, Watershed Ecosystem

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Introduction

The Water-Energy-Food nexus (WEF) has been initially introduced in the international community as an adaptive management approach in response to climate change (Schmidt and Matthews, 2018; Zhang et al., 2018; Endo et al., 2015). In fact, the goal of adaptation is to reduce vulnerability to climate and human impacts in terms of the security challenges of water, energy, and food. It is therefore essential for sustainable development (Rasul and Sharma, 2016). The first report on the need for the WEF nexus model dates back to the Bonn Conference in 2011 focused on the interdependency of water, energy, and food security that need to be explicitly identified in decision making (Mohtar et al., 2015). By definition, nexus consists of basic concepts for the dynamics of water, energy and food inter-relationships (Elsayed et al., 2018; Smajgl et al., 2016). Numerous studies have been reported on water-energy-food nexus (e.g., Daher et al., 2019; Li et al., 2019; Serrano-Tovar et al., 2019; Hussien et al., 2018;), water–food–energy nexus (e.g., Moioli et al., 2018), water-energy nexus (e.g., Murray and Holbert, 2020; Liu et al., 2019; Pan et al., 2018), food-energy nexus (e.g., Amjath-Babu et al., 2019), and food-energy-water nexus (e.g., Nie et al., 2019). Applying a food-energy-water nexus approach for land use optimization (Nie et al., 2019) reported that the framework works effectively to balance multiple objectives and benchmarks the competitions for systematic decisions. The water-energy-food nexus assessment of a local case study of desalination system in the Canary Islands, Spain, was investigated by Serrano-Tovar et al. (2019). This latter study illustrated the potential of the multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM) in providing an integrated assessment of the WEF nexus in relation to sustainability. The illustration of the MuSIASEM approach showed the possibility of producing a robust quantitative estimate of the energy, water, and food nexus utilizing insights from complexity theory. This was accomplished through establishing connections over processors conveying information referring to distinct dimensions and scales of analysis.

Heated discussion is normally found in agricultural land use in watersheds presenting several challenges within the WEF nexus at the local and global scales (Gulati and Pahuja, 2015). In fact, the soil is the main medium for plant growth and the substrate for all biogeochemical/ physical processes. Hence, soil forms the foundation of any food–water–energy nexus system. However, few studies (e.g., Hatfield et al., 2017; Lal et al., 2017; Subramanian and Manjunatha, 2014) have examined the interaction among the WEF nexus components with soil as the only factor supporting productions in the ecosystems. Agricultural land use in watersheds as the user of the soil resources for meeting food and energy security is one example of a social-ecological system, and its inherent synergies and trade-offs are best explained by the nexus-thinking approach in order to maintain the stability of the system (Mwale and Mirzabaev, 2015). Actually, considering the nexus approach with sufficient concentration on the soil is essential as the foundation of the future of mankind. Therefore, the current study aims to review and analyze the existing literature on WEF nexus approach at different scales throughout the globe and to suggest supplementary ideas for better applicability of WEF nexus framework for integrated watershed management.

Materials and Methods

To conduct the study, a quantitative approach was applied through collecting secondary data and information available in publications and on the web. Towards this, specific scientific keywords viz. food nexus, water-energy nexus, water-food nexus, energy-food nexus, water-energy-food nexus, and soil nexus in connection with other nexuses were searched from the time of launching WEF nexus at the Bonn 2011 Nexus Conference up to now. The corresponding literature was then scrutinized in terms of geographical distribution and fundamental concepts. In addition, the worldwide interest over time (2011 to 2019) to water, energy, and food

security nexus was obtained using Google Trends Web that is shown in Figs. 1 and 2. Ultimately, the important findings, outcomes, and suggestions were concluded to accordingly propose new ideas and approaches to be efficiently adopted at watershed scales.

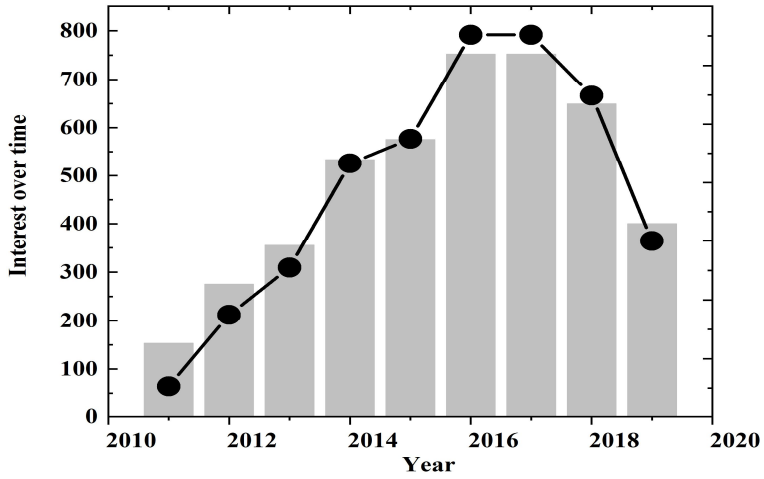

Figure 1. The global interest over time to water, energy and food security nexus from 2011 to 2019

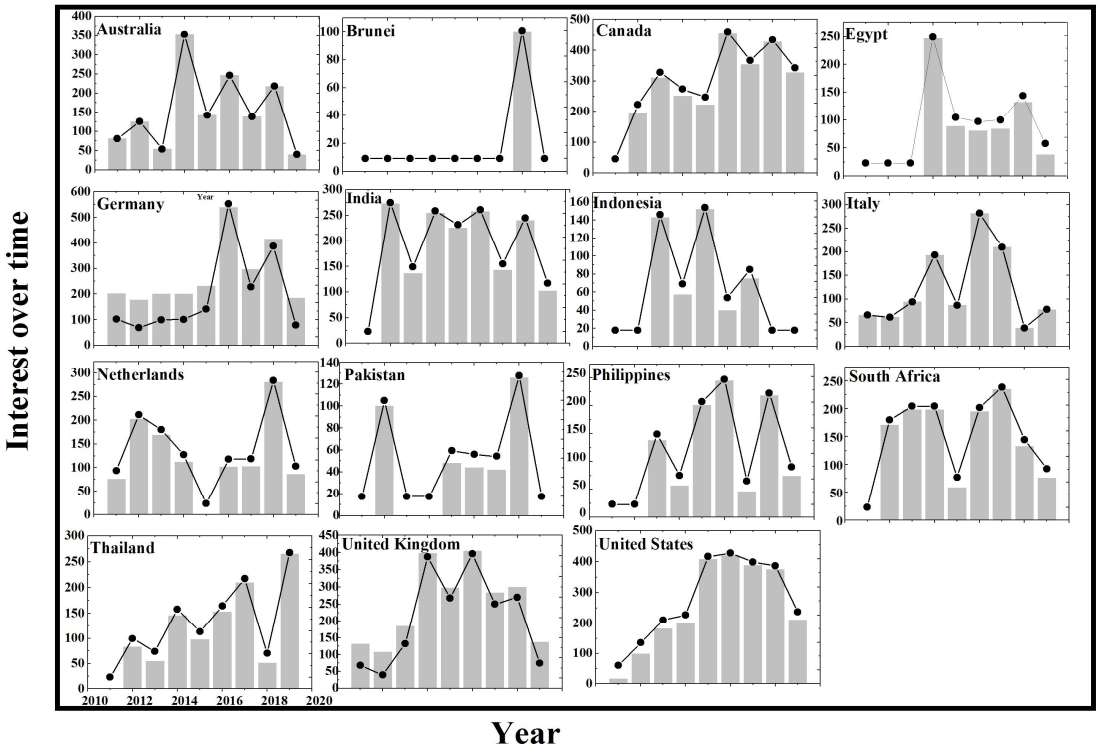

Figure 2. Interest over time of water, energy and food security nexus in the different countries from 2011 to 2019

Results and Discussion

As per procedure explained above, some 203 articles and documents were found dealing with WEF nexus in different viewpoints. One of the reasons for more attention to the concept of WEF nexus in the world (Figure 1 and 2) may be attributed to increasing demands for food, energy, and water without

considering negative environmental impacts and the complex and interrelated nature of our global resource systems. The recognition of the interlinked nature of water, energy and food and a lack of a unified framework to make appropriate trade-offs is then vital (Nie et al., 2019; Shannak et al., 2018; Endo et al., 2017). In this context, Daher et al. (2019) confirmed that a nexus approach would be useful in accounting for the associated trade-offs and competition among water, energy and food systems. In the same vein, eight various types of nexuses consisting of water-food nexus, water-energy nexus, water-energy-food nexus, climate relation with water-energy-food nexus, water-food-energy-ecosystems nexus, water-energy-land-food nexus, food-energy-environment nexus, water-soil-waste nexus were categorized. Among them, 10 articles had a close linkage with water–food, 49 with water-energy, 119 with water-energy-food, six with water-food-energy-ecosystems, five with water-energy-land-food, three with food-energy-environment, three with water-soil-waste and eight with climate. The details are depicted in Figure 3.

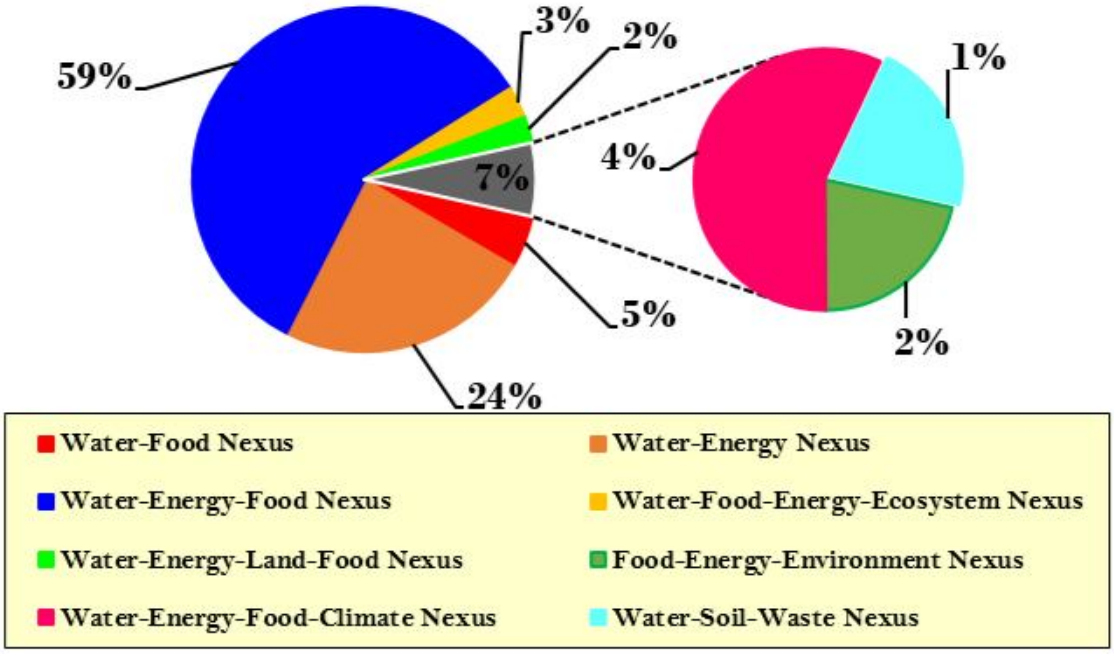

Figure 3. Number of documents in the field of different nexuses from 2011 to 2019

Endo et al. (2015) reported that the environmental importance of the water-food nexus is identified through examining food imports and the virtual water nexus. They further pointed out that the water-food nexus led to improvement in the efficiency of utilization of green water or the rainwater, prevention of depletion of residual soil moisture and reduction of the use of water through a shift to low water consuming crops. Schemes on the aforesaid water-energy nexus were classified based on the assessment of biofuel, use of abandoned mines for water storage, use of solar pumps and quench systems for water pumping and billing, wastewater treatment plant and promoting well-regulated on-site treatment technologies. The environmental activities of the water–energy–food nexus were promoted through analyzing the sugar for producing energy like alternative energy, concentrated solar power and woody biomass for producing electricity, investigating the land and water requirements for producing bioethanol maize, developing trench system to recharge underground aquifers and reduction in irrigation application to lower energy consumption and carbon emission of groundwater use. Finally, climate-related nexus of environmental activities was considered to reduce vulnerability to climate change-induced disasters and environmental degradation in

the long term and analyzing specific data such as 280 aquifers. In light of the evidence, the endeavors have also been made in different regions of Asia (Central, South, Southeast and East; 38%), Australia, Africa (North, South and East), North America (USA, Mexico and Canada; 31%), South America (Brazil), Europe (UK, Italy, Germany, Spain, Sweden and Greece; 23%) and Oceania as demonstrated in Figure 4.

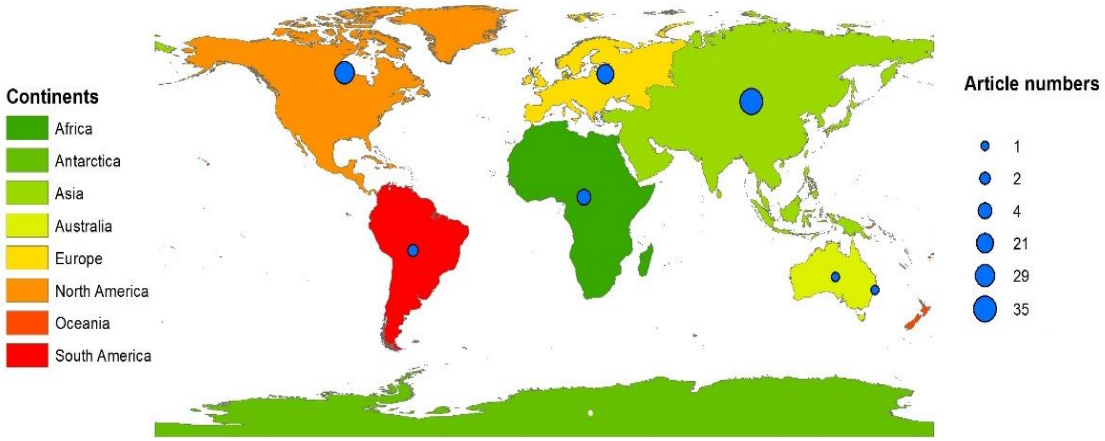

Figure 4. Geographical distribution of documents on WEF nexuses in different regions of the world

The water, energy and food security have so far been essentially demanded because of unbalanced access. In hotspot regions such as South Asia (where lack of land is also becoming an issue) and sub-Saharan Africa, large sections of the population remain marginalized and deprived of their human rights and development opportunities (Hoff, 2011). So, new approaches such as WEF nexus are needed. Taniguchia et al. (2017) reported measures of water, energy, and food security for thirty two countries in the Asia Pacific Region. They recognized a high diversity of sources of water in the US and Philippines, and low diversity of food sources in the US, Canada, and Indonesia. A major challenge in South African policymaking is resource management in isolation, without recognizing the use of water, energy, and land by other sectors. Moreover, it has been predicted that the climate change will have a negative impact on the availability of resources in South Africa, where ecosystem services, rainfall frequency and distribution, and natural disasters influenced the security of the ecosystem (Mabhaudhi et al., 2018). As it is seen in Figure 3, the maximum studies have been conducted in the field of traditional water-energy-food nexus whilst the minimum attention has been paid to more comprehensive and recently introduced water-energy-food-ecosystem nexus. It clearly verifies the need for integration of important chapters for comprehensive management of the ecosystem. Water, energy, ecosystems, and agriculture have always been recognized as the key sectors and related to an Integrated Water Resource Management approach. The water-energy-food-ecosystem nexus approach concurrently estimates multiple sectors and their evolution (De Strasser et al., 2016).

Besides, Figure 4 also shows that the developed countries have worked on WEF nexus during the last decade and it is being gradually extended to developing and undeveloped countries where the consideration on making the balance in different resources under an umbrella framework like WEF nexus is really needed. Thus, we see a general tendency of Asian, North American and European countries to the water, energy, and food nexus. In Asian countries, increased population and the need for more meat to feed the nation is likely to grow demand for energy. Furthermore,

Chinese state-owned enterprises have emerged as among the most active investors in the Mekong Basin hydropower development and current frameworks are partial as they largely represent a water-centric perspective (Matthews and Motta, 2015). Hence, the Nexus provides a relevant starting point for promoting sustainable development in the Mekong. Also, the water-energy-food nexus is an approach for sustainable agriculture and food security as for instance, in Qatar, the goal is food self-sufficiency (Mohtar and Daher, 2014). So, it is concluded that a regional integrative approach would be beneficial in the water-energy-food nexus. In North America, due to population and economic growth and increasing urgency arising from water and energy crises in the next half-century, requires more serious attention to the nexus approach. Asia, Africa and Latin America are hotspots promoting hydropower development with capacity expansion, while Europe and North America focus on performance improvement and environmental impacts mitigation for further interpretation of the results as emphasized by Zhang et al., (2018). The compounding effects of climate change, habitat loss, pollution, and overexploitation make the individual management of these three vital resources incompatible with rapidly growing populations and resource-intensive lifestyles. So, Nexus thinking is a critical tool to capture opportunities for watershed sustainability. Moreover, providing optimal solutions for power generation, fuel and water supply, capacity expansion and greenhouse gas emission control are needed for developed countries. For example, in the UK the mobilization of the nexus approach can best be understood as symptomatic of broader global science-policy trends, including an increasing emphasis on integration as an ideal, an emphasis on technical solutions to environmental problems, achievement of efficiency gains and "win-win" results, and a preference for technocratic forms of environmental managerialism (Cairns and Krzywoszynska, 2016).

Conclusion

Nowadays, it is essential for all scientists and managers to discuss the changes occurred in the world and the regions, and consider water, energy, and food in an integrated manner. After evaluating and analyzing the current status of research on different types of nexus, we propose that other important ecosystem elements like soil has to be considered in future directions for WEF nexus research. Understanding the interconnectedness and tradeoffs among distinct sections of the nexus with sufficient focus on the soil will lead to the ability to face current and projected global challenges. Otherwise, economic inequalities and the encouragement of a short-term response to production and consumption will threaten long-term sustainability creating serious risks. In addition, the watershed is a complex and dynamic ecosystem, the best, and most suitable scale for the management of soil-water-energy-food (SWEF) providing a holistic approach considering all ecosystem processes. In brief, the SWEF nexus at the watershed scale is important for transformative, sustainable solutions to maximize human-environmental security and decrease vulnerability. However, the complexity of the nexus system has not yet been appropriately clarified throughout the globe. In addition, each country or region has specifically considered own resource nexus problems. It is therefore advised that the SWEF nexus to be progressively addressed, dealing with resource nexus problems in general and attempting to draw comprehensive conclusions.

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