Chapter

Introductory Chapter: Addressing Past Claims and Oncoming Challenges for Irrigation Systems

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1. Introduction

Water-agriculture nexus is context dependent (water availability and water use depend on spatial and temporal issues), socially constructed (multiple stakeholders' perceptions and interests interact), and technically uncertain (benefits from new technologies are difficult to be estimated and duly evaluated). This means that irrigation systems should be analyzed as hydrosocial cycles [1], which likewise takes into account all of these issues including how water management and water governance are conceived and how climate change impacts could be addressed through a "nexus" approach [2]. In few words, irrigation systems are under pressure to produce more food with lower supplies of water [3]. According to this, water availability and water consumption [4], food productivity and food security [5], environmental awareness [6], population growth [7], rural development [8], and climate change [9] are issues to be considered when irrigation systems are promoted, developed, and managed both globally and locally.

2. Irrigation water consumption: calling for concerted effort

Globally, irrigation was by far the largest water consumer with a share ranging over time about 90% of global water consumption [10]. In addition, agriculture is the sector most affected by water scarcity, as it accounts for 70% of global freshwater withdrawals [11]. In fact, agriculture is both a cause and victim of water scarcity, as the excessive use and degradation of water resources is threatening the sustainability of livelihoods dependent on water and agriculture [12]. Furthermore, as the largest water user globally and a major source of water pollution, agriculture plays a key role in tackling the looming water crises. What can agriculture do to address water scarcity in the context of climate change, while ensuring food and nutrition security? What can irrigation offer to alleviate the impacts and reduce the risks of water scarcity? Both questions have been directly addressed through the achievement of the 2030 Agenda for Sustainable Development and the promotion of Sustainable Development Goals (SDG) [13]. These include the adoption of SDG-6 ("*Ensure availability and sustainable management of water and sanitation for all*") and SDG-2 ("*End hunger, achieve food security and improved nutrition, and promote sustainable agriculture*"). Both goals are an opportunity to be engaged with key water-scarce countries to inform and orient national policies toward effective, sustainable models, and technologies of water management and food security [14]. Furthermore, both are in line with the Paris

Agreement of the United Nations Framework Convention on Climate Change (UNFCCC)—entered into force on 2016 with the aim of, among others, recognizing the fundamental priority of safeguarding food security and ending hunger and reducing the particular vulnerabilities of food production systems to the adverse impacts of climate change. Furthermore, the Paris Agreement promotes better resilience of socioeconomic and ecological systems through economic diversification and sustainable management of natural resources [15].

3. Irrigation operation: the need for being climate smart

Observed climate change impacts are already affecting food security through increasing temperatures, changing precipitation patterns, and greater frequency of some extreme events [16]. Increasing temperatures are affecting agricultural productivity in higher latitudes, raising yields of some crops (maize, cotton, and wheat), while yields of others are declining in lower-latitude regions [17]. Changes in land use and an increasing demand for water resources have affected the capacity of ecosystems to sustain food production, ensure freshwater resources supply, provide ecosystem services, and promote rural multifunctionality [18]. According to the special report "*Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and governance gas fluxes in terrestrial ecosystems*"—recently published by the Intergovernmental Panel on Climate Change (IPCC)—agriculture, forestry, and other land use (AFOLU) activities accounted for 23% of total net anthropogenic greenhouse gas emissions (GHGs) by the period 2007–2016. However, agriculture is not only a contributor to climate change, it will also be severely affected by climate change [19]. Moreover, some effects of warming on crop yields, increased pest occurrences, and the effects of extreme events (e.g., floods, storms, and droughts) on agricultural production are already observed [20]. Although farmers have long adapted to environmental conditions, the severity of the predicted climate changes may be beyond many farmers' current ability to adapt and improve their agricultural production systems and livelihoods [21]. While increased food production will have to be done in the face of a changing climate and climate variability [22], agricultural and irrigation systems should reduce their carbon cost and its contribution to GHG [23]. In order to address this gap, increasing interest has been focused on ensuring that both agriculture and irrigation become climate smart as a driven factor to ensure food security, improve rural livelihoods, and alleviate environmental risks for small-scale farmers [24]. The multi-dimensional aspects of agricultural production under climate change are captured by the climate-smart agriculture (CSA), an approach in which agriculture is transformed and reoriented under the projected scenarios of climate change [25]. The CSA has three concurrent objectives: (i) sustainably increasing farm productivity and income, (ii) increasing adaptive capacity to climate change, and (iii) reducing GHG emissions [26]. In fact, CSA seeks to enhance productivity, water conservation, livelihoods, biodiversity, resilience to climate stress, and environmental quality [27]. Despite the recognized importance of CSA by the Global Alliance for Climate Smart Agriculture (GASCA) and a range of international and national initiatives focused on climate-smart technologies (CST), the dissemination and uptake of climate smart technologies, tools, and practices is still largely an ongoing, challenging process [28]. At this point, some questions should be addressed:

- To what extent is irrigation an enabler of other CSA technologies and under what conditions (soil/market/demography/crop/water management, etc.)?

- Which type of irrigation technology is more climate resilient to extremes and long-term change (watershed management, small-scale pumping, small reservoirs, etc.)?

- Who benefits and what are the implications for food security and food sovereignty if irrigation becomes an integral part of CSA technologies?

According to the FAO-IPCC Expert Meeting on "Climate Change, Land Use and Food Security" celebrated in 2017 [29], to secure a resilient food system under climate change requires a range of appropriate sustainability metrics to better support integrated and multidisciplinary scenario analyses combining socio-economic and ecological dimensions. Among other measures, experts highlighted (1) the need to integrate technical and economic assessments when measuring the impact of improved water use efficiency (maximizing "crop per drop") vs sustainable water use (optimized renewable use of water within a river basin) and (2) the promotion of participatory research to develop frameworks to manage water, land, agroforestry, and crops under different water demand, supply, and pricing conditions.

4. Irrigation impacts and risks: fixing the environmental limits

According to the Organization for Economic Co-operation and Development (OECD), a key challenge for the agriculture sector is to feed an increasing global population, while at the same time reducing the environmental impact and preserving natural resources for future generations. Agriculture can have significant impacts on the environment [30]. While negative impacts are serious and can include pollution and degradation of soil, water, and air [31], agriculture can also positively affect the environment, for instance by trapping GHG within crops and soils [32], or mitigating flood risks through the adoption of certain farming practices [33]. In recent years, there have been some encouraging signs that the agriculture sector and irrigation activities are capable of meeting its environmental challenges. In particular, farmers have made improvements in the use and management of nutrients [34], pesticides [35], energy [36], and water [37], using less of these inputs per unit of land and adopting more environmentally beneficial practices, such as conservation tillage [38] or soil nutrient testing [39]. Taking into account the urgent challenge of matching demand for food for a larger population using the same land footprint, the Global Water Forum (an initiative of the UNESCO Chair in Water Economics and Transboundary Water Governance) discussed the expansion of irrigated areas and their affection to agroecosystems and sustainability [40]. To mitigate that risk while responding to increased global water needs, agricultural management options could include blending different qualities of water sources [41], matching irrigation methods or promoting deficit irrigation [42], and selecting salt tolerant crops [43]. Whatever methods and strategies are used to increase food production, they must also preserve soil ecological functionality and minimize environmental risks.

5. Irrigation adaptation: water management and alternative water sources

As freshwater resources are under increasing stress in several world regions, with a mismatch between availability and demand and temporal and geographical scales [44], new approaches have been promoted in order to guarantee the agricultural activity (by considering social and economic issues) and irrigation sustainability (by addressing environmental issues) in an integrated way. The first approach is focused on putting more attention to understanding current water management and promoting transition to more adaptive water regimes that take into account environmental, technological, economic, institutional, and cultural characteristics of river basins. This implies a paradigm shift in water management from a prediction and control to a management as a social-learning approach [45]. The second approach has been focused on water availability. That is, the general decreasing trend in water availability and the need for sustainable use of available water resources have led regional and national governments worldwide to seek alternative water sources [46], putting special attention to wastewater reuse and water desalination. The first one is not a "new" water source, but rather a way to waste able to be used for a new water demand. It differs to increase water supply measures such as seawater desalination, which in effect includes a new input to the water cycle [47]. Both concepts, water reuse and seawater desalination, are limited by different key barriers. The first barrier is that their management is more complex than the management of conventional water resources, but also their cost is more expensive than the cost of "environmental" water sources—rivers—due to its conveyance, storage, and distribution in dedicated network infrastructure [48]. The second barrier is that both the public and farmers negatively percept alternative water sources by highlighting their environmental and health risks instead of their benefits (especially in the case of wastewater resources) [49–52]. Furthermore, although there are rules and regulations clearly focused on ensuring standards on food security, yuck factor currently justify the negative to use alternative water resources [53]. It should be noted that addressing the last two barriers are not solely related to technical issues, but to social issues. According to this and irrespective of scientific and engineering based considerations, farmers' opposition and public rejection has the potential to cause water reuse and water desalination projects to fail, before, during, or after their execution [54]. In fact, reuse and desalinated water schemes may face public opposition resulting from a combination of prejudiced beliefs, fear, attitudes, lack of knowledge, and general distrust, which, on the whole, is often not unjustified, judging by the frequent (and highly publicized) failures of wastewater treatment facilities worldwide.

6. Irrigation challenge: welcome to the Anthropocene

The need for capturing, storing, cleaning, and redirecting freshwater resources in efforts to increase water availability even with irregular river flows and unpredictable rainfall has been one of the main challenges of humanity [55]. Resulting impacts on water productivity and security schemes (which requires waterworks from storage and distribution such as dams, pipelines, canals, and water transfers) [56] means that the water cycle has been increasingly controlled by human activities and this was the hallmark of the new geological epoch called the "Anthropocene" [57]. This term is currently used (and discussed) to encompass different geological, ecological, sociological, and behavioral dynamics in recent earth history. The origins of the concept, its terminology, and its socio-political implications have also been widely discussed across the scientific community [58]. In fact, for some authors, the commitment to define a new geological period responds to the *hydrocentric* approach that emerged over the past two decades [59, 60], which focused on managing water resources as a natural water environment duly protected. Some evidences suggest, however, that what are needed are rather *hydrosupportive* approaches in which water management is performed to achieve social goals, which may include, among other factors, the ability to sustain environmental functions [61]. The concept, popularized by the Dutch atmospheric chemist and Nobel Prize-winning Paul Crutzen, is defined to describe a new geologic era caused by the drastic effect of human action on the earth. Taking into account the transdisciplinary nature of the concept, the analysis of human-water interactions requires the collaboration between natural sciences and the humanities, which must simultaneously explore the geophysical, social, and economic forces that shape an increasingly human dominated global hydrologic (and hydrosocial) system [62].

According to the report "*Adapt Now: A global call for leadership on climate resilience*" published on 2019 by the Global Commission on Adaptation, adapting the planet's water resources and systems to the Anthropocene and the new climate reality is a formidable task. Furthermore, it is the main opportunity to improve ecosystems management, grow eco-friendly economies, boost agricultural efficiencies, and planning for natural risks (floods and droughts) from nature-based solutions [63]. In fact, 10 years ago, a report from the Food and Agriculture Organization of the United Nations (FAO) untitled "*Climate change, water and food security*" clearly promoted the applicability of different adaptation measures that deal with climate variability and build upon improved land and water management practices. These measures imply a good understanding of the impact of climate change on available water resources and on agricultural systems, and a set of policy choices, and investments and managerial changes to address them. Some year later and in order to respond to water-food nexus challenges in a coordinated and effective manner, the FAO has developed the *Global Framework for Action to Cope with Water Scarcity in Agriculture in the Context of Climate Change*. It calls for urgent action to cope with water scarcity in agriculture in the context of climate change and growing competition for water resources. The *Global Framework for Action* recognizes the intricate links between climate change, water scarcity, sustainable agriculture, and food security and the importance of addressing these holistically. Its objective is to strengthen the capacity to adapt agriculture to the impacts of climate change and water scarcity and thereby to reduce water-related constraints to achieving the food security and sustainable development goals. This framework is based on the premise that a sustainable pathway to food security in the context of water scarcity lies in maximizing benefits that cut across multiple dimensions of the food-water-climate nexus [64]. This means enabling sustainable agricultural production while reducing vulnerability to water scarcity and optimizing the climate change adaptation and mitigation benefits [65].

Taking into account both the adaptation capacity of irrigation systems from its socio-ecological nature and the requirements for addressing oncoming climate challenges, this book is the first attempt at bringing several fields together to analyze irrigation by combining technical, social, and management approaches.

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