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Review

Water Scarcity and Future Challenges for Food Production

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Abstract: Present water shortage is one of the primary world issues, and according to climate change projections, it will be more critical in the future. Since water availability and accessibility are the most significant constraining factors for crop production, addressing this issue is indispensable for areas affected by water scarcity. Current and future issues related to "water scarcity" are reviewed in this paper so as to highlight the necessity of a more sustainable approach to water resource management. As a consequence of increasing water scarcity and drought, resulting from climate change, considerable water use for irrigation is expected to occur in the context of tough competition between agribusiness and other sectors of the economy. In addition, the estimated increment of the global population growth rate points out the inevitable increase of food demand in the future, with an immediate impact on farming water use. Since a noteworthy relationship exists between the water possessions of a country and the capacity for food production, assessing the irrigation needs is indispensable for water resource planning in order to meet food needs and avoid excessive water consumption.

Keywords: internal and external water resources; agricultural water demand; land grabbing; water footprint; water for food; sustainable water use

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1. Introduction

As the most important resource for life, water has been a central issue on the international agenda for several decades. Nowadays, many areas of the world are affected by water scarcity [1]. The projected increase of the world population growth rate [2] suggests that higher food demand is expected in the future, with a direct effect on agricultural water usage. In addition, as a result of the increased water scarcity and drought due to climate change [3], extensive water use for irrigation is expected to occur in the context of increasing competition between agriculture and other sectors of the economy. In order to cope with future estimates of water shortages, some measures aimed at streamlining and optimizing the efficiency of water consumption in the agricultural sector are critical in view of the large volumes of water required for the production of crops. Irrigation is used to replace losses due to crop evapotranspiration and to achieve full production under the given growing environment [4]. Irrigation, however, is also applied to combat pests through products diluted in the water, for frost protection of sensitive crops, to apply nutrients that are dissolved in the water, to improve the physical properties of land, to remove excess salinity from the soil and to modify the soil pH.

Since the balance between water demand and water availability has reached critical levels in many regions of the world and increased demand for water and food production is likely in the future, a sustainable approach to water resource management in agriculture is essential. The sustainable water management concept refers to all practices that improve crop yield and minimize non-beneficial water losses. In addition, biofuel production is increasingly competing with food production, and this trend could reduce water resources and food availability [5]. The implications for water for food are evident.

In this context, the aim of this article is to provide a broad review of several water-related issues, including virtual water trade, water availability and future demand scenarios, and to propose potential solutions to cope with water scarcity for food production.

2. Basic Concepts of Water Resources

In addition to its quantitative and physical dimensions, the concept of water resources comprises also qualitative socio-economic and environmental dimensions. Water is divided in two types of resources: renewable and non-renewable water resources.

Groundwater and surface water, such as the average flow of rivers on a yearly basis, are considered renewable water resources, whereas deep aquifers, which do not have a significant replenishment rate on the human time scale, are deemed non-renewable water resources [6].

Water is also distinguished in terms of supply. Blue water is the liquid water above and below the ground (rivers, lakes, groundwater), and green water is the soil water in the unsaturated zone derived from precipitation [7]. The portion of water that is directly used and evaporated by rainfed agriculture, pastures and forests is defined as green water. Thus, green water flow has two components: The productive part, or the transpiration involved in biomass production in terrestrial ecosystems, and the non-productive part, or evaporation [8]. Blue and green water are both viewed as renewable resources in the broad sense; however, only blue water is assessed in the strict sense.

A method for assessing the renewable water resources by country was first described in 1996 [9]. It computes the total renewable water resources (TRWR) of a country and assesses the dependency ratio from neighboring countries. The TRWR are the sum of internal renewable water resources (IRWR) and external renewable water resources (ERWR). Those indexes have been defined by FAO [6], and a brief description follows. IRWR are the volume of water resources (surface water and groundwater) generated from precipitation within a country or catchments. Surface water flows can contribute to groundwater replacement through seepage in the riverbed. On the other hand, aquifers can discharge into rivers and contribute to their base flow, the only source of river flow during dry periods. Sometimes, these two concepts overlap, although surface water and groundwater are typically studied separately. ERWR are considered resources that enter from upstream countries through rivers or aquifers. ERWR are separated into two categories: natural and actual ERWR. The natural ERWR are equal to the volume of the average annual flow of rivers and groundwater that enter into a country from neighboring countries, while the actual ERWR consider the incoming flow and outflows that derive from upstream and downstream countries through formal or informal treaties. Therefore, the actual resource is related to the amount of flow shared with neighboring countries (geopolitical country constraints).

All of these considerations and analyses are necessary to understand how countries depend on the water resources of their neighbors. The ratio between the ERWR and TRWR gives the dependency ratio of a country, an indicator that expresses the part of the water resources originated outside the country. The dependency ratio ranges between 0%, where there is no dependency on external water, to 100%, where a country totally depends on the water resources from neighboring countries [6].

The total freshwater resources in the world are estimated to be in the order of 43,750 km^3 $year^{-1}$, distributed throughout the world; at the continental level, America has the largest share of the world's total freshwater resources, with 45%, followed by Asia with 28%, Europe with 16%, and Africa with 9% [6]. In terms of resources per inhabitant in each continent, America has 24,000 m^3 $year^{-1}$, Europe 9300 m^3 $year^{-1}$, Africa 5000 m^3 $year^{-1}$ and Asia 3400 m^3 $year^{-1}$ [6].

However, at the country level, there is an extreme variability in terms of TRWR. For 19 countries or territories (e.g., Morocco, Algeria, Bahrain, Jordan, Kuwait, Libyan Arab Jamahiriya, Maldives, Malta, Qatar, Saudi Arabia, United Arab Emirates, Yemen), the TRWR per inhabitant are less than 500 m^3 [6], the threshold that corresponds to the water scarcity levels proposed by Falkenmark [7], with Kuwait probably being the worst case (10 m^3 per inhabitant) [6].

In terms of IRWR, North Africa and the Middle East are the most critical cases, with values that range from 0 to 1000 m^3 $year^{-1}$ per person (Figure 1), where the threshold of 1000 m^3 per inhabitant is considered the water stress level.

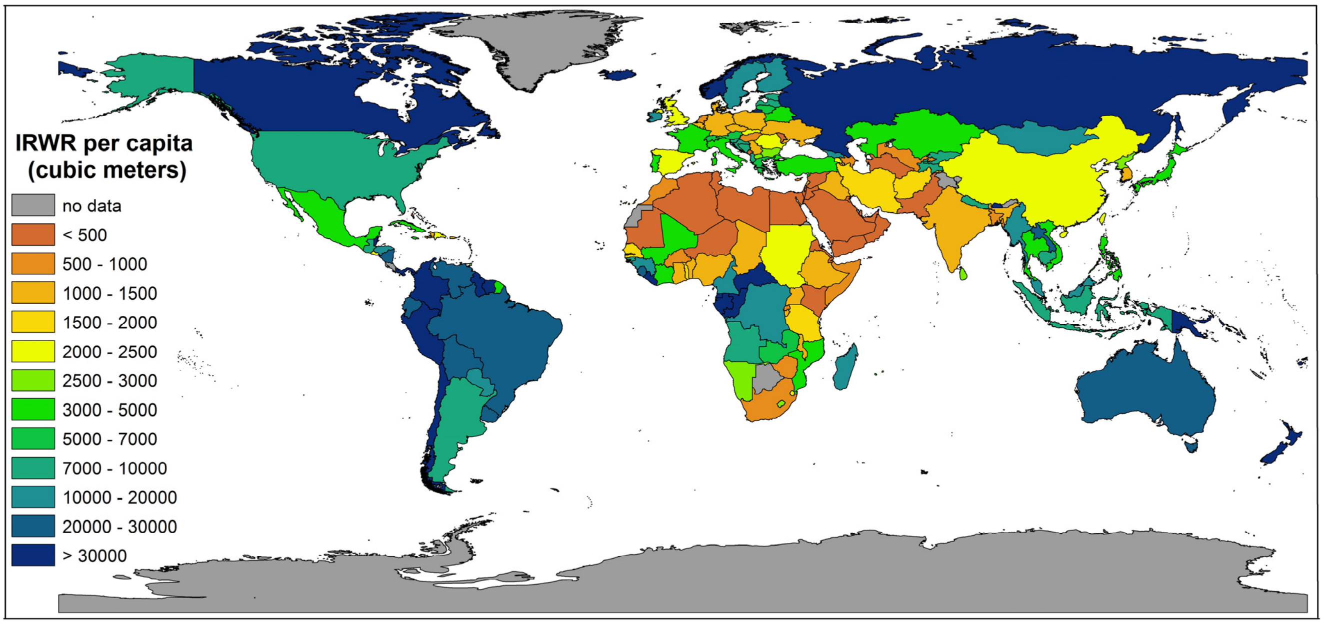

Figure 1. World map of internal renewable water resources (IRWR) per country in 2012 (data from World Bank Group [10]).

3. Growing Demand of Water for Food

Nowadays, "scarcity" is one of the adjectives most related to the word "water"; thus, many studies and projects focusing on the assessment of global water demand and its availability have been developed. In fact, water demand has reached critical levels in many areas of the world, especially in countries with limited water availability. The misuse of water resources, the lack of infrastructures to supply water and also climate change are some of the reasons for water scarcity, despite the vast amount of water on the planet. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report states that the magnitude of stress on water resources is expected to increase as a consequence of climate change, future population growth and economic and land-use change, including urbanization. According to the scenarios described in the IPCC Special Report on Emissions Scenarios [3,11], changes in precipitation and temperature may lead to changes in runoff and water availability, which, in turn, could affect crop productivity [3]. The physical, chemical and biological properties of freshwater lakes and rivers will be affected by the increase in temperature [3]. This change is predicted to negatively affect many freshwater species and community and habitat composition. Moreover, as a consequence of sea level rise in low-lying coastal areas, the quality of freshwater aquifers is influenced by the intrusion of saline water.

The rising atmospheric CO_2 concentration is associated with higher temperatures and changes with precipitation patterns. Changes in precipitation patterns, the intensity and frequency of extreme events and soil moisture, runoff and evapotranspiration fluxes have already been observed, and more important changes are expected in the future [11]. The increase of precipitation at high latitudes and parts of the tropics and the decrease in some subtropical and lower mid-latitude regions are consistently projected by climate model simulations for the 21st century [11]. Sillmann and Roeckner [12] estimated a significant increase in extreme precipitation events in most regions of the world, especially in areas already relatively wet under present climate conditions. Analogously, dry spells are expected to increase, particularly in those regions that are characterized by dry conditions in the present-day climate, such as European regions [12]. Altered frequencies of extreme events, associated with melting of winter snow and with consequent reduced storage of precipitation as snow, result in decreased water availability and significant impacts on crop yield. In addition, the combined effect of higher temperature and the reduction of water availability in regions affected by falling annual or seasonal precipitation leads to the increase of crop evaporative demands, with the consequent reduction in crop yield and agricultural productivity, where temperature constrains crop growth [13].

On the other hand, several studies confirm a positive crop reaction to increased levels of CO_2 in the absence of climate change [14–16]. In fact, higher CO_2 concentrations reduce the stomatal conductance and transpiration rates of crops [17], enabling the improvement of water use efficiency and root water uptake capacity [18]. The positive effect on crop yield, due to the CO_2 enrichment on plant growth and development, is called the CO_2 fertilization effect [19].

Nowadays, 22% of the land surface is used for pastures and rangelands, and another 12% is used for agriculture [20]. Globally, water consumption for all sectors amounts to 9% of total freshwater resources in the world [21], with agriculture being the largest user, in turn accounting for approximately 70% of total water withdrawals [21,22], which is equivalent to 2700 km^3 $year^{-1}$ (including losses) [21]. Similarly, Shiklomanov [23] estimated that the agricultural sector receives up to two-thirds of the total water withdrawals and accounts for almost 90% of the total water consumption in the world. More than 80% of global agricultural land is rainfed, thus only green water is consumed [24]. However, irrigated land, representing only 18% of global agricultural land, produces about half of the world's total supply [24]. This is because yields of irrigated crops are on average 2–3 times more than their rain-fed counterparts. The lowest values for specific annual fresh water withdrawals in agriculture (Figure 2) are observed in Northern Europe, between 0%–30% of the total water withdrawals. In Asia, Africa, Central and South America, the values for specific water withdrawal range from 50% to 100%. Alexandratos and Bruinsma [25] report that in the aforementioned countries, which have a great variety of climatic conditions, crop composition and watering techniques, irrigation water withdrawals range between 96 km^3 in Sub-Saharan Africa and 708 km^3 in East Asia; the highest values for specific water withdrawal are observed in South Asia, with 913 km^3.

Globally, at least 7130 km^3 of water are needed to satisfy crop evapotranspiration losses in agriculture, considering both blue and green water (irrigation delivery and on-farm system losses excluded) [24]; however, a considerable variation between regions is noticed (Figure 3). Irrigation is quite important in North Africa, the Middle East, the Near East and southern Asia, where more than 75% of food is produced by means of irrigation (Figure 3), and blue water crop evapotranspiration is about half of the total food crop evapotranspiration (Figure 3, pie charts). These regions, together with the Mediterranean region, Australia, the USA, Mexico, Northeastern Brazil and the west coast of South America, are considered water-stressed basins [1]. In addition, an increase in irrigation water demand, particularly in the aforementioned areas, is projected because of climate change [3].

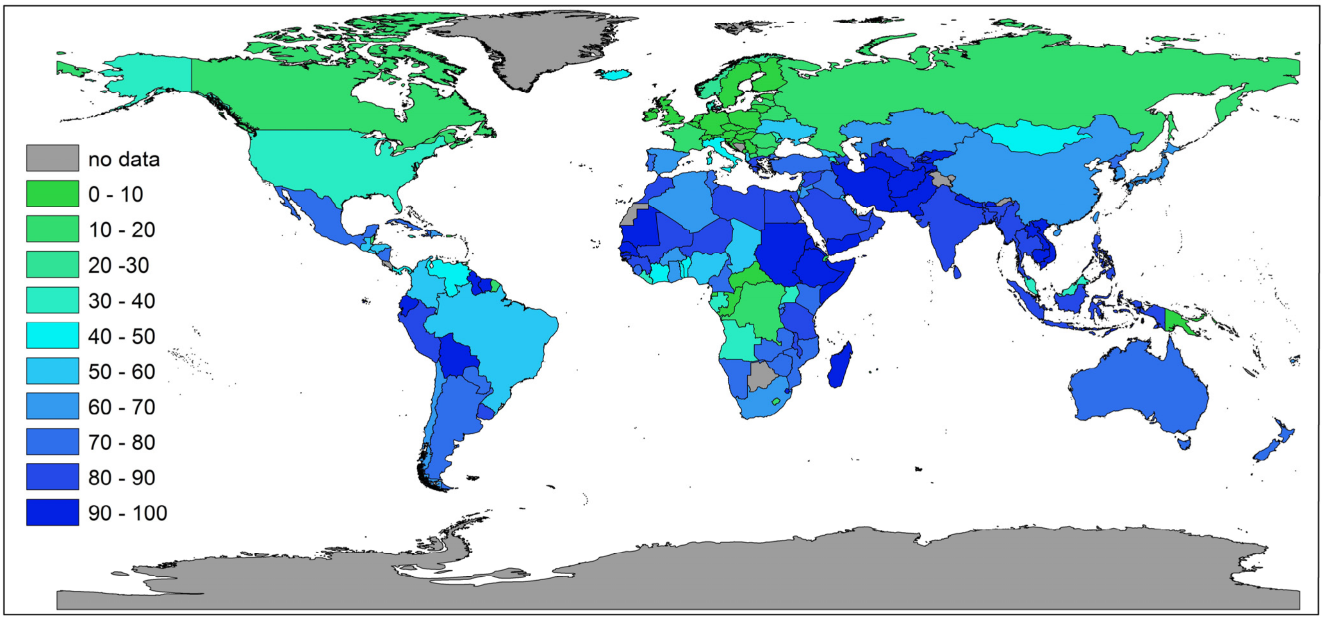

Figure 2. Annual fresh water withdrawals in agriculture per country (%), referring to total water withdrawals in 2012 (data from World Bank Group [10]).

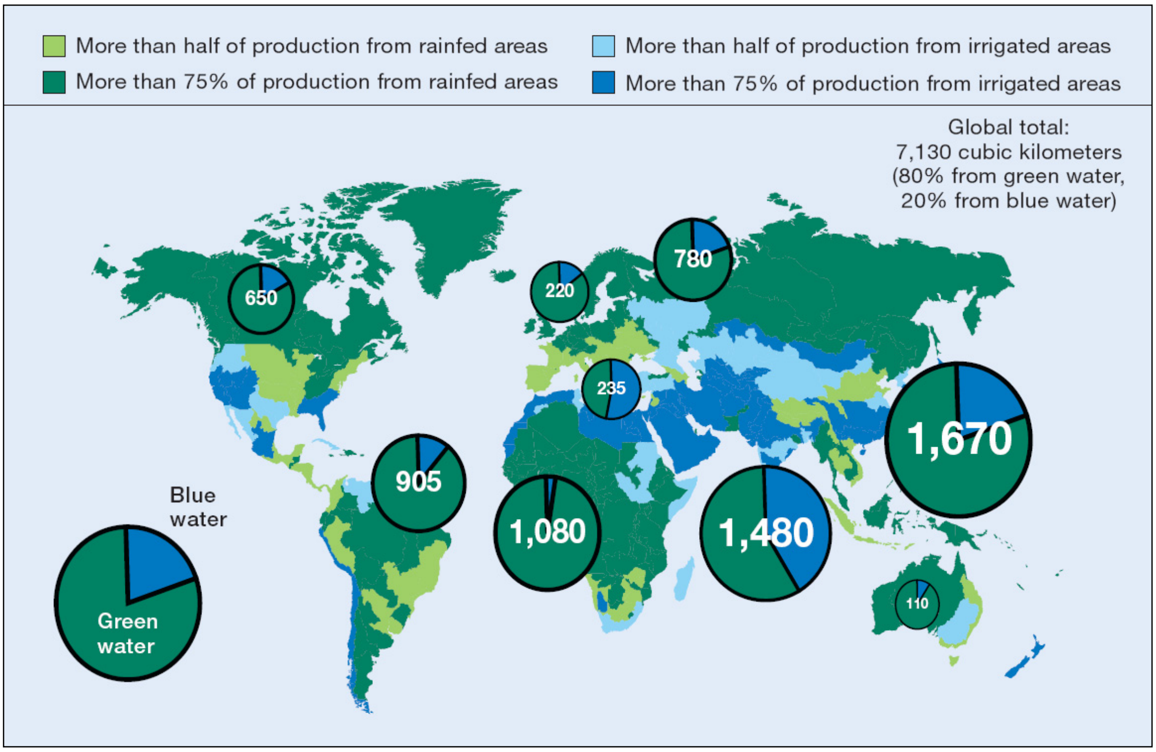

Figure 3. Food crop evapotranspiration from rain and irrigation (km^3) and production (%) by region. Note: production refers to the gross value of production. The pie charts show total crop water evapotranspiration in cubic kilometers by region. From the International Water Management Institute (IWMI) analysis done for the comprehensive assessment of water management in agriculture using the Watersim model (source: IWMI [24]; reproduced by permission from IWMI).

Fischer *et al.* [26] estimated future increases in irrigation water requirements by over 50% in developing regions and by about 16% in developed regions. In this study, the largest relative increases of irrigation water requirements are projected to occur in Africa (+300%) and Latin America (+119%) from 2000 to 2080. Furthermore, the most critical values of annual renewable freshwater resources are observed in the Middle East and Africa. In fact, the estimates made by Wallace [27] highlighted that the populations in the Middle East and southern Africa in the nineties of the last century had between 1000 to 2000 m^3 of water per year. Whereas, during the same period, populations in the North African belt from Morocco to Egypt (including Sudan) had less than 1000 m^3 of water per person per year. By 2050, the available water per capita per year will drop below 1000 m^3, not only in the North African belt, but also in eastern and southern Africa and the Middle East [27].

In addition, some countries that are projected to experience physical water scarcity are already experiencing economic water scarcity (Figure 4). Economic water scarcity occurs when investments on infrastructure development (e.g., water supply pipe networks and reservoirs) needed to cope with the growing water demand are constrained by financial, human or institutional capacity [24]. Even though infrastructure might exist, high vulnerability to seasonal water fluctuations can lead to water scarcity for agriculture and domestic purposes. When infrastructure is inadequate, malnutrition can exist, even when water resources are abundant relative to water needs.

Future population growth is another factor to consider. With world population expected to grow by around 2.3 billion people between 2009 and 2050 [2,28,29], up to two-thirds of the world population could experience water scarcity over the next few decades [1,27,30–36]. As estimated by Roetter and Van Keulen [28], the median population growth projection for 2025 is between is 8.3 and 7.3 billion, compared with the present 6.4 billion, with an annual growth rate of approximately 1% between now and 2025 in Asia, where the population will grow by 650 million people. At present, nearly 80% of the world's population is exposed to high levels of threat to water security [37], and the increase of world population will have a significant impact on water usage for food. Under a pessimistic low yield scenario, de Fraiture and Wichelns [38] estimated that 53% more crop water consumption and 38% more land are needed to achieve food production goals in 2050.

4. More Water for Food or Fuel?

Greater pressure on the global land and freshwater resources results from the increase of global food demand. Since 2007–2008, the convergence of global crises in food, energy, finance and the environment has driven a dramatic revaluation of land ownership [39]. More specifically, Rulli *et al.* [40] pointed out that the increased need for land is due to the increased global demand for biofuel, because of the growth of oil prices, the 2007 changes in the United States policy on bioethanol use and the 2009 Renewable Energy Directive adopted by the European Union. In order to satisfy their food and energy needs, some governments acquire lands in a foreign country creating, thus, the so-called "land grabbing" phenomenon. Zoomers [41] defined "land grab" as the production of food for export by finance-rich, resource-poor countries and biofuels for export. When the grabbed land is irrigated, land grabbing includes the acquisition of available freshwater resources, so that the ERWR in the surrounding and downstream areas is reduced, which can lead to water stress [42].

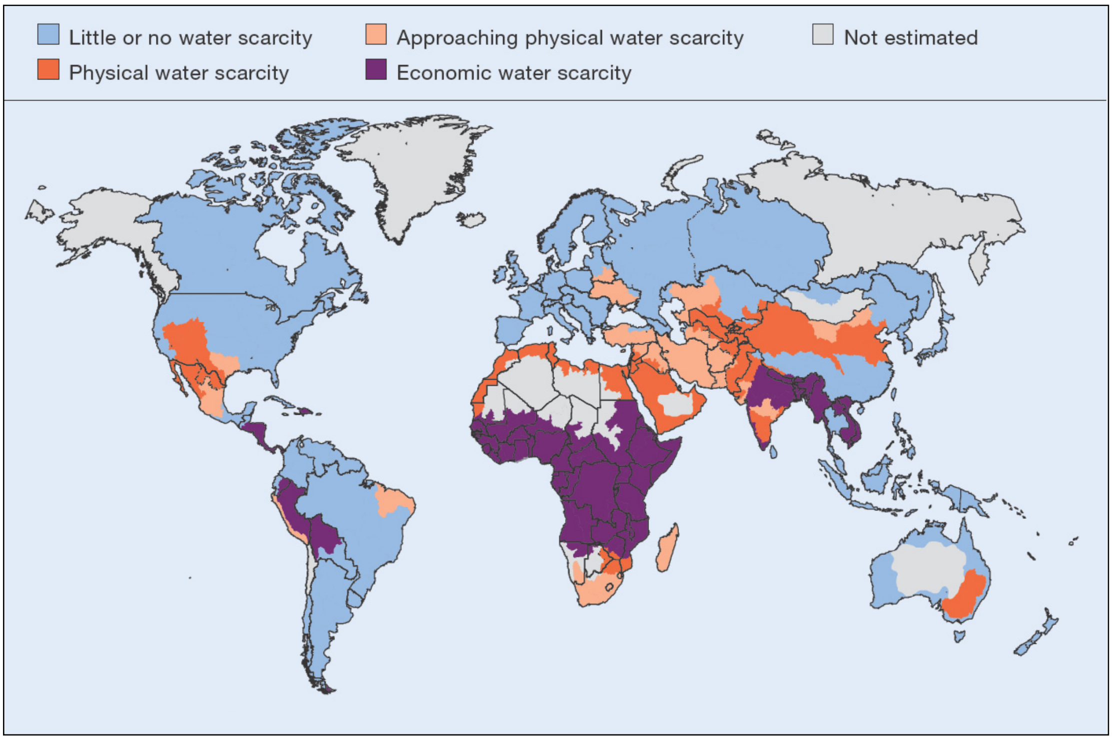

Figure 4. Areas of physical and economical water scarcity at the basin level in 2007. Definitions and indicators: (1) Little or no water scarcity. Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes; (2) Physical water scarcity (water resource development is approaching or has exceeded sustainable limits). More than 75% of river flows are withdrawn for agriculture, industry and domestic purposes (accounting for recycling return flows). This definition, relating water availability to water demand, implies that dry areas are not necessarily water scarce; (3) Approaching physical water scarcity. More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future; (4) Economic water scarcity (human, institutional and financial capital limit access to water, even though water in nature is available locally to meet human demands). Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists. From the International Water Management Institute analysis done for the comprehensive assessment for water management in agriculture using the Watersim model (source: IWMI [24]; reproduced by permission from IWMI).

The assessment of the water use for agricultural production in the top 24 grabbed countries [40] shows that most grabbed countries (Figure 5) are located in physical or economic water stress areas (Figure 4). Indonesia, the Philippines and the Democratic Republic of Congo show the highest grabbed green water rates, while Tanzania and Sudan are the countries most affected by blue water grabbing. Moreover, the amount of grabbed green water in Sudan and Tanzania is equal to 2.45×10^{10} m^3 $year^{-1}$ and 1.56×10^{10} m^3 $year^{-1}$, respectively, and this comprises almost half the volume of green water necessary to produce food [44] (4.84×10^{10} m^3 $year^{-1}$ in Sudan and 3.77×10^{10} m^3 $year^{-1}$ in Tanzania). The situation is even worse in the Democratic Republic of Congo, where the volume of grabbed green water is almost equal to the amount of green water for food production.

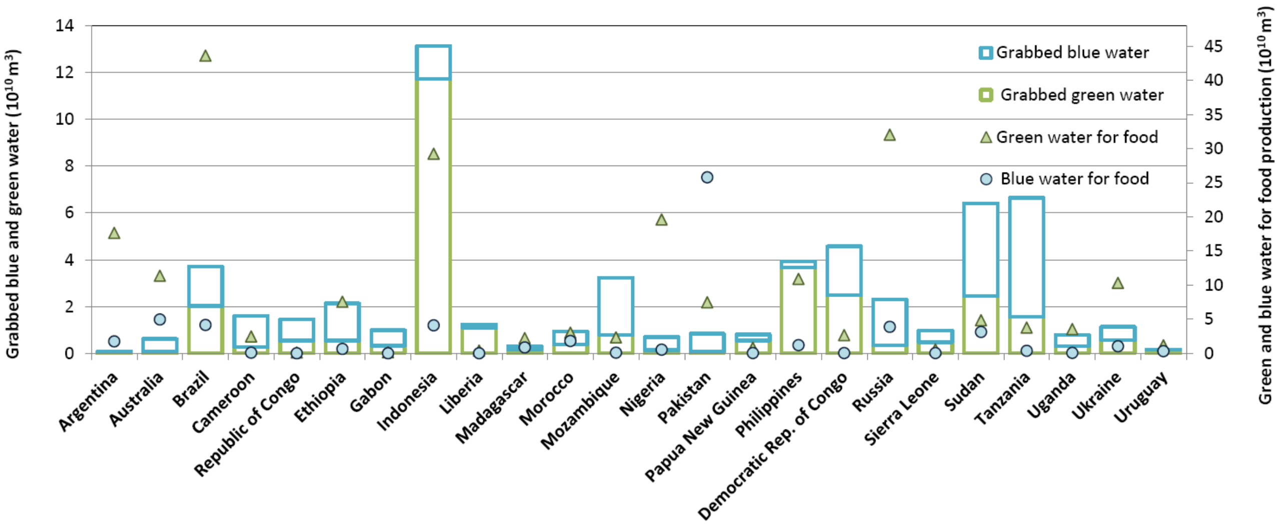

Figure 5. Volumes of grabbed water and water necessary for food production in the 24 most land-grabbed countries. Blue water accounts also for water losses due to soil evaporation and drainage, and it is computed as the ratio between irrigation needs and the irrigation efficiency (Data from Rulli [40], FAO [21], and Mekonnen and Hoekstra [44]).

Crops that have multiple uses (food, fuel, industrial material) are grown with the aim to exploit the grabbed land under several economic points of view. Because these crops and commodities can be, or are thought to be, flexibly inter-changed, they are deemed “flex” crops [43]. These include, but are not limited to, soya (food, biodiesel), sugarcane (food, ethanol), oil palm (food, biodiesel, commercial/industrial uses) and corn (food, ethanol); cassava, coconut, beets, rapeseed and sunflower are other potential flex crops [43].

Commercially-grown biofuels need fertile lands and water, with a consequent competition of these two resources between fuel and food-crop production [5]. In addition, the large-scale monocropping of exotic species is leading to biodiversity loss [45], and while biofuel projects target water resources (especially in Africa), as opposed to the belief that biofuels utilize African marginal lands [46], there is the possible reduction of access to land by smallholder farmers [5].

Therefore, the expansion of crop production for biofuels increases the use of freshwater with the consequent worsening of water stress in some countries [47].

5. How Much Water Does Food Cost?

A significant connection exists between a country’s capability to produce food and its renewable water resources availability. In order to have a consumption-based indicator of water use that could provide useful information, the “water footprint” concept was introduced. Water footprint is defined as the total volume of freshwater that is used to produce the goods and services consumed by the people of the nation [48]. Mekonnen and Hoekstra [49] quantified that the global average water footprint in the period 1996–2005 was 1385 m^3 per year per capita, and about 92% was related to the consumption of agricultural products. Moreover, it was estimated that the largest contribution to the water footprint of the average consumer was due to cereal products (27%), followed by meat (22%) and milk products (7%), where the contribution of different consumption categories to the total water footprint varied across countries [49]. In fact, in a range between 550 and 3800 m^3 year^{-1} per capita, at the lowest rank was the Democratic Republic of Congo (552 m^3 year^{-1} per capita), while Bolivia (3468 m^3 year^{-1} per capita), Niger (3519 m^3 year^{-1} per capita) and Mongolia (3775 m^3 year^{-1} per capita) were the countries with the highest water footprint values [49].

Since not all goods consumed in a particular country are produced locally, the water footprint comprises the use of water resources that derive from other countries in addition to domestic water [50]. Thus, the "water footprint" and "virtual water" concepts are strictly related. Virtual water is defined as the volume of both blue and green water consumption required to produce commodities traded to an importing or exporting nation (or any region, company, individual, *etc.*). Allan [51] termed such food imports as "virtual water imports", due to the fact that they are equivalent to a transfer of water to an importing country. Through importation of food and certain commodities that would otherwise consume great quantities of water, such as agricultural and livestock products, countries affected by water scarcity could alleviate this issue [52]. Hanasaki *et al.* [53] showed that the global virtual water export of five crops (barley, maize, rice, soybean and wheat) and three livestock products (beef, pork and chicken) is 545 km^3 year^{-1}. Of the total virtual water exports, 61 km^3 year^{-1} (11%) were blue water and 26 km^3 year^{-1} (5%) were nonrenewable and nonlocal blue water [53].

The net virtual water import flows are mostly observed in Japan, North Africa, Mexico, the Middle East, South Korea and Europe, while Australia, North and South America and southern Asia are major exporters of net virtual water [54] (Figure 6).

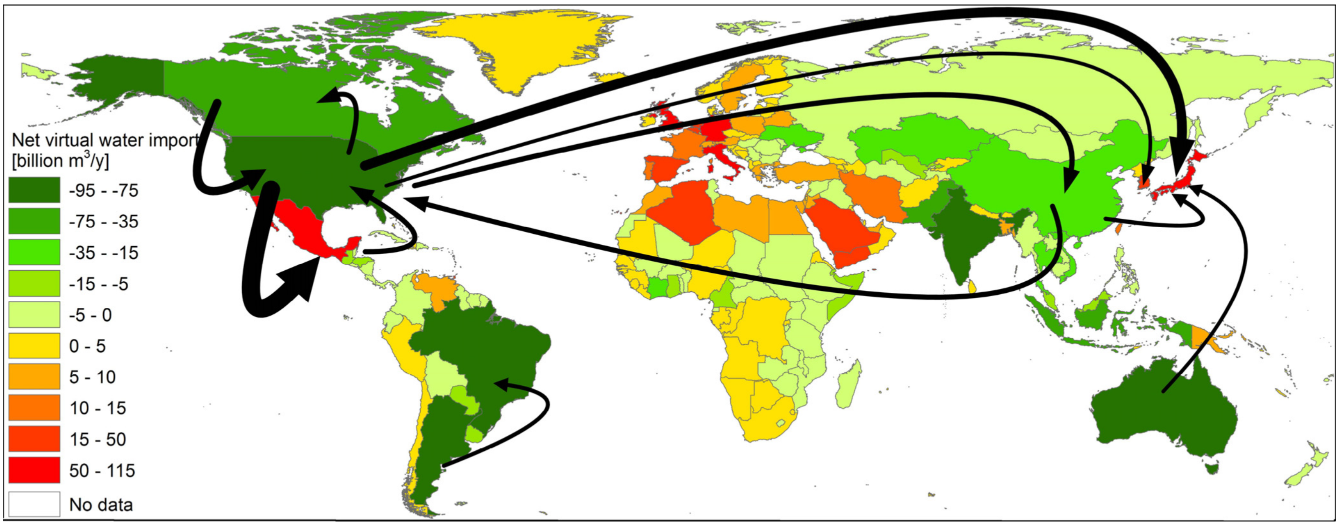

Figure 6. Virtual water balance per country and the direction of gross virtual water flows related to trade in agricultural and industrial products over the period 1996–2005. The gross virtual water import is calculated by multiplying import volumes of various products by their respective product water footprint in the nation of origin. The gross virtual water export is found by multiplying the export volumes of the various export products by their respective product water footprint. Only the largest gross flows (>15 Gm^3 per year) are shown (Source: Hoekstra and Mekonnen [54]; reproduced by permission from the Proceedings of the National Academy of Sciences of the United States of America (PNAS)).

Cereal imports have played a key role in compensating local water shortages. Many countries in Africa and Asia, which are considered water-scarce continents because of the high concentration of countries affected by this problem [55,56], are net importers of cereal grains. Especially in several countries, where the irrigated areas expanded relatively rapidly in the last two decades, e.g., Egypt, Algeria, Libya, Israel, Morocco and Tunisia, a significant import of cereals was still observed. Yang and Zehnder [57] reported that in 1998–1999, cereal imports accounted for 52% of the total supply in the six countries. Under the baseline scenario, the cereal demand is projected to increase by 38% by 2020, whereas, under the increased consumption scenario, cereal demand will rise up to 47% by 2020. This means that some countries will be unable to meet future food demands without importing, which will cause several poor, populous countries to drop below the water scarcity threshold due to population growth and the depletion of fossil groundwater. Therefore, the international trade in agricultural products and food grains has played and will continue to play a critical role in water-scarce countries.

At the same time, virtual water imports pose several issues on the concept of "food security". The World Food Summit of 1996 established that "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" [58]. Three essential concepts are at the benchmark of the food security theory: (i) Food availability (the amount of food constantly available); (ii) Food access (the ability to have sufficient resources to obtain appropriate food for a healthy diet); and (iii) Food utilization (the use of appropriate products based on basic knowledge of nutrition, water and adequate sanitary conditions) [58].

While the "virtual water" import demand can have an adverse impact on the stability of the world food economy, on the other hand, food imports are a valid way to create economic growth in water-scarce countries, maximizing the value of their limited water supplies for other economic sectors. The necessity of countries to meet their food requirements, however, creates uncertainties, mostly related to the policies of exporting countries.

6. Sustainable Use of Water in Agriculture: More Food with Less Water

As pointed out in the previous sections, the import-export of virtual water could help to alleviate the future increase of water demand for food due to climate change impacts and population growth. Increasing water scarcity and drought, however, point to the necessity for a more sustainable approach to water resource management in agriculture at the global, regional and local level [59]. In addition, in some countries (e.g., the Mediterranean region), irrigation is mainly applied during the summer, which coincides with the main tourism period and results in a competition between these two sectors. This aspect highlights the necessity of water resource planning to allocate water supply among different economic sectors.

The first step in the agricultural sector is to compute how much water is needed by crops with regard to climate conditions. Some techniques, such as soil monitoring, lysimeter, eddy covariance, the Bowen ratio and surface renewal, are used to monitor and measure irrigation needs. While the monitoring approach may require delicate and expensive sensors or the assistance of experts, the application of models (e.g., soil water balance models) could provide a low-cost method for on-farm and regional systems for computing the crop water requirement and estimating the depth of water storage required to satisfy the agricultural demand. Once the crop water requirement is known, improving the efficiency of the irrigation application is a key strategy for water savings in agriculture. The term "efficiency" is commonly used to indicate "the level of performance" of a system.

In the agricultural sector, the concept of "water use efficiency" is often used to highlight the relationship between crop growth development and the amount of water used. Sinclair *et al.* [60] described plant water use efficiency as the ratio of biomass accumulation (expressed as carbon dioxide assimilation), total crop biomass or crop grain yield to transpiration by the crop. This plant physiology concept differs from the on-farm irrigation concept of the efficient use of irrigation water to produce a crop. To avoid confusion between the plant-based water use efficiency and the agronomy/engineering concept of applying irrigation water efficiently to optimize production, the term "water productivity" is often used to quantify the efficient use of irrigation water. The water productivity is expressed as the agricultural production per unit of water applied, diverted or consumed (rainfall and/or irrigation), to produce a crop [61]. As pointed out by Playán and Mateos [61], an increase in water productivity ameliorates gains in crop yield, while reducing the amount of irrigation water contributing to unrecoverable losses. The increase of water productivity could be the solution for food needs accompanying the projected population growth.

Nowadays, many strategies are implemented to improve water productivity, starting with the optimal choice of irrigation system, followed by the application of the proper irrigation scheduling in terms of both timing and quantity of water applied and concluding with the choice of the best crop management with regards to the soil and climate conditions.

The selection of the proper irrigation system depends on several factors, such as water availability, crop selection, soil characteristics (deep percolation, runoff, evaporation rate and topography) and the associated installation and maintenance costs. The main systems are separated into gravity systems, where water moves naturally over the soil surface due to the force of gravity, and pressurized systems. There are several measures of irrigation efficiency that are described in Burt *et al.* [62], and readers are referred to that publication for more details. An important measure to evaluate the performance of irrigation systems is the application efficiency (AE), which is defined as the ratio of the average depth of irrigation water contributing to the target divided by the average depth of irrigation water applied. The ratio is multiplied by 100 to express the AE as a percentage. The target depth is generally based on the soil water depletion before irrigation or a smaller amount to adjust for rainfall contributions. The target can also include excess water for reclamation or for salinity control.

Many studies have been conducted to determine the AE for different systems, and the overall conclusion is that pressurized systems are generally more efficient for transporting water to crops than traditional gravity systems [63]. In recent years, several irrigation systems have significantly improved the application efficiency at the farm level, enhancing irrigation water management. Although the traditional gravity approach is still widely used, particularly in the southern part of Europe, it is gradually being replaced [64]. Nevertheless, the application efficiency of a system depends on the amount and timing of water applied, as well as on the considered crop, soil and climate conditions.

To maximize crop yield and meet the crop water requirement, irrigation to refill soil water depletion is typically applied at each irrigation. This approach is valid for most field crops and many orchard crops. Holzapfel *et al.* [65], however, indicated that providing deficit irrigation to some tree and vine crops can lead to more profits due to a small reduction in yield, but better quality and reduced water application.

Improving the crop technical efficiency may be another solution to overcome the water for food issue. The choice of the best cultivar, such as more drought-tolerant cultivars, or crop management with regards to the soil and climate conditions can provide a method to improve water productivity. For instance, shifting the planting date in response to climate change can be beneficial, especially for those crops with a spring-summer growing season. Simulations of irrigation requirements under climate change scenarios, where the planting date was shifted by a month or even earlier in the spring, showed optimal results [66,67] for some crops. In fact, planting earlier in the spring increases the length of the growing season, and it can increase the potential yield if the soil moisture is adequate and the risk of heat stress is low [68]. Otherwise, earlier planting combined with a short-season cultivar would give the best assurance of avoiding heat and water stress [69]. Kucharik [70] observed that the current yield trend toward earlier maize planting dates appears to have contributed to recent gains in yield between 19% and 53% in several states in the northern and western portions of the Corn Belt (Nebraska, Iowa, South Dakota, Minnesota, Wisconsin, and Michigan). The shorter growing season and earlier planting dates have significantly improved the yield by 0.06 to 0.14 Mg ha^{-1} for each additional day of earlier planting [70].

7. Conclusions

Water is a key resource for the development of any human activity. In many countries, the available water supply and the uneven distribution of these resources in time and space are pressing issues. It is projected that a large share of the world's population, up to two-thirds, will be affected by water scarcity over the next several decades. The availability of water for farming is an essential condition for achieving satisfactory and profitable yields, both in terms of unit yields and quality. The correlation between the expected increase in irrigation water requirements, critical values of renewable freshwater resources and economic water scarcity, indicates the necessity for regional policy coordination and careful water management strategies at the national and site levels. Such policy coordination and water management strategies could avail themselves of scientific research that is actively involved in dealing with water scarcity. Currently, there are many studies on strategies and policies for water supply management, biomolecular and genetic research to find more drought-tolerant cultivars, on climate change and its impact on future irrigation requirements and yield and on climate adaptation strategies. More investments in infrastructure development (*i.e.*, dams and water supply pipe networks) would help future populations cope with the growing water demand and where an uneven distribution of precipitation in time is expected. These investments are especially needed in those countries affected, or projected to be affected, by water scarcity.

The application of efficient water management strategies is a key element to increase water productivity. In addition to the assessment of crop management strategies, the improvement of irrigation systems and irrigation schemes can lead to a more efficient and sustainable agricultural water management. In addition, models may serve as a decision support tool for regional and on-farm system management to develop strategy scenarios for sustainable farming systems. Government funds (e.g., the Common Agricultural Policy rural development regulation of the European Union) already play a major role in financing measures to reduce agricultural water use, and they may be more effective in the future. Finally, attentiveness to the choices of appropriate policy measures in agriculture and the implementation of efficient farmer advisory schemes are critical for future economic growth in countries affected by water scarcity.

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Author Contributions

All of the authors contributed to the development of this paper; Noemi Mancosu gathered all data information and prepared the first draft of the paper; Richard L. Snyder, Gavriil Kyriakakis and Donatella Spano improved and revised the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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